

SATA 6Gb/s 1.8" SSD Manual



The SATA Element SSD is a non-volatile, solid-state storage device. With its Serial ATA interface and industry-standard form factors, it is a drop in replacement for hard disk drives. The Element SSD delivers extremely high levels of performance, reliability and ruggedness for I/O intensive or environmentally challenging applications.

Manual	1/2/2014
PSFS1XXXXGXXXX	Viking Technology
Revision B7	Page 1 of 60

Revision History

Date	Revision	Description	Checked by
3/26/12	A	Release of new format. Changed supply voltage to +/-5%. Deleted part numbers VRFS11100GAIPSTF (1.8"). Added notes for operating temperature. Updated SMART attribute table. Corrected SMART threshold table. Added "Ambient" to temperature range, Added info on Immediate Standby timings.	
5/01/12	A1	Added part number VRFS11240GFCyMz. Revised mechanical drawing and SMART attributes. Revised the attributes for VRFxxGJxx. Add mass/weight of SSD.	
6/05/12	A2	Added note on enterprise vs client	
6/07/12	A3	Added note features not available for industrial versions, which are VRFS1xGA, VRFS1xGK and VRFS1xGM. Added a note on SMART attributes. Added note on enterprise vs client	
9/27/12	A4	Update PN table to VT PSGC 9.18.12. Added Capacity LBA table. Adjusted indentation. Added performance for xxGK and xxKM	
10/17/12	A5	Added performance for xxGK and xxKM	
4/9/13	B	Update Company name. Added xxTJxx PN's Changed altitude specification and add note on storage temperature Removed all PN's with an "A" or a "B" in the controller location of the part number in the Order Information table Add more detail to Block diagram, added current and power tables for 480GB drive. Added VRFS11025GFIRSTH and VRFS11050GFIRSTH to PN table along with config #'s.	
4/19/13	B1	Add power consumption information (based on client and enterprise SSD's (ie: VRFS11480GMCVMTHP1, VRFS11400GFCVETHE1)	
6/19/13	B2	Remove xxxGMxx from PN table due to controller going EOL. Add low power mode in xxxGFxxx feature table	
7/17/13	B3	Added VRFS11100GFITM. Revised SMART attributes to worst=1	
8/22/13	B4	Revised the weight for client and enterprise SSD's. add photo to 1 st page	
9/12/13	B5	Revised PN Table	

Date	Revision	Description	Checked by
10/22/13	B6	Revised description of SMART Attribute 13 (Soft read error rate)	
1/2/14	B7	Updated datasheet format	Bob Desmarais

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Manual	1/2/2014
PSFS1XXXXGXXXX	Viking Technology
Revision B7	Page 4 of 60

Ordering Information: Element 1.8" SSD Family

Viking High Performance Solid-State Drive Ordering Information

Part Number	Form Factor	Temperature	NAND type	User Capacity	Platform	Interface
VRFS11100GFCxMyz	SSD 1.8" 5.0mm	Com (0 to +70 °C)	MLC	100GB	Enterprise	SATA 6Gb
VRFS11100GFCxMyz	SSD 1.8" 5.0mm	Com (0 to +70 °C)	MLC	100GB	Enterprise	SATA 6Gb
VRFS11200GFCxMyz	SSD 1.8" 5.0mm	Com (0 to +70 °C)	MLC	200GB	Enterprise	SATA 6Gb
VRFS11200GFCxMyz	SSD 1.8" 5.0mm	Com (0 to +70 °C)	MLC	200GB	Enterprise	SATA 6Gb
VRFS11400GFCxMyz	SSD 1.8" 5.0mm	Com (0 to +70 °C)	MLC	400GB	Enterprise	SATA 6Gb
VRFS11400GFCxMyz	SSD 1.8" 5.0mm	Com (0 to +70 °C)	MLC	400GB	Enterprise	SATA 6Gb
VRFS11100GFCxEyz	SSD 1.8" 5.0mm	Com (0 to +70 °C)	eMLC	100GB	Enterprise	SATA 6Gb
VRFS11200GFCxEyz	SSD 1.8" 5.0mm	Com (0 to +70 °C)	eMLC	200GB	Enterprise	SATA 6Gb
VRFS11400GFCxEyz	SSD 1.8" 5.0mm	Com (0 to +70 °C)	eMLC	400GB	Enterprise	SATA 6Gb
VRFS11025GFCxSyz	SSD 1.8" 5.0mm	Com (0 to +70 °C)	SLC	25GB	Enterprise	SATA 6Gb
VRFS11050GFCxSyz	SSD 1.8" 5.0mm	Com (0 to +70 °C)	SLC	50GB	Enterprise	SATA 6Gb
VRFS11100GFCxSyz	SSD 1.8" 5.0mm	Com (0 to +70 °C)	SLC	100GB	Enterprise	SATA 6Gb
VRFS11025GFIxSyz ⁸	SSD 1.8" 5.0mm	Ind (-40 to +85 °C)	SLC	25GB	Enterprise	SATA 6Gb
VRFS11050GFIxSyz ⁸	SSD 1.8" 5.0mm	Ind (-40 to +85 °C)	SLC	50GB	Enterprise	SATA 6Gb
VRFS11100GFIxMyz	SSD 1.8" 5.0mm	Ind (-40 to +85 °C)	MLC	120GB	Enterprise	SATA 6Gb
VRFS11120GFIxMyz	SSD 1.8" 5.0mm	Ind (-40 to +85 °C)	MLC	120GB	Enterprise	SATA 6Gb
VRFS11240GFIxMyz	SSD 1.8" 5.0mm	Ind (-40 to +85 °C)	MLC	240GB	Enterprise	SATA 6Gb
VRFS11120GKIxMyz	SSD 1.8" 5.0mm	Ind (-40 to +85 °C)	MLC	120GB	Client	SATA 6Gb
VRFS11240GKIxMyz	SSD 1.8" 5.0mm	Ind (-40 to +85 °C)	MLC	240GB	Client	SATA 6Gb

Notes:

- 1) Usable capacity based on a level of over-provisioning applied to wear leveling, bad sectors, index tables etc.
- 2) Higher capacity points may be available based on customer application. Consult your local Viking Field Application Engineer.
- 3) SSD's ship unformatted from the factory unless otherwise requested.
- 4) x= Lowercase character(s) for NAND capacity. Contact Viking for what "x" represents in the PN.
- 5) y and z = Lowercase character(s) for NAND vendor and die revisions and /or for customer specific locked BOMs
- 6) 1 GB = 1,000,000,000 Byte and not all of the memory can be used for data storage. Usable capacity
- 7) 1Sector = 512 Byte.
- 8) VRFS11025GFIRSTH config ID=25287, VRFS11050GFIRSTH config ID =25307

Viking's solid state drives are available in Enterprise and Client versions:

Enterprise SSD – An Enterprise SSD contains hardware and firmware that detect and manage power failures. This allows the drive to flush the controller cache and harden data to NAND flash. No data is lost or corrupted.

Client SSD – A Client SSD does not include power failure detection or management features. MLC NAND, as opposed to SLC NAND, can become corrupted if power is removed during a write, also known as lower page corruption. Therefore, a Client SSD using MLC NAND is well-suited in a system that already manages power fail events, allowing for graceful SSD shutdown. Accordingly, system support should include issuing a Standby Immediate command to the SSD while maintaining power for at least 50ms.

If a Client drive with MLC NAND is used in a system that does not manage power failures and shutdowns, there is a small chance of data corruption. Viking Client SSD's take sophisticated hardware and firmware measures to prevent or mitigate such issues making the chance of corruption very small.

If the SSD controller detects data corruption, the drive will be locked. The only way to recover the drive is to return it to the factory for reprogramming; all data will be lost.

Product Picture(s)



Manual	1/2/2014
PSFS1XXXXGXXXX	Viking Technology
Revision B7	Page 7 of 60

Table of Contents

1	INTRODUCTION	11
1.1	Features	11
1.2	Block Diagram	14
1.3	SATA Interface for VRFS1xGA, VRFS1xGJ	15
1.4	SATA Interface for VRFS1xGF, VRFS1xGK, VRFS1xGM	15
2	PRODUCT SPECIFICATIONS	15
2.1	Capacity-LBA	15
2.2	Performance	16
2.3	Timing	18
2.3.1	STANDBY IMMEDIATE Command	18
2.4	Electrical Characteristics	19
2.4.1	Absolute Maximum Ratings	19
2.4.2	Supply Voltage	19
2.4.3	Supply Current	19
2.4.4	Power Consumption	19
2.5	Environmental Conditions	20
2.5.1	Temperature and Altitude	20
2.5.2	Shock and Vibration	21
2.5.3	Electromagnetic Compatibility	21
2.6	Reliability	22
2.6.1	Data, MetaData, and Firmware Code Protection	22
2.6.2	Intelligent Read Disturb Management	24
2.6.3	Intelligent Write Operation Management	24
2.7	Data Security	25
2.7.1	Secure Erase Support	26
3	MECHANICAL INFORMATION	28
3.1	Element SSD Physical Dimensions	28
3.2	Element SSD Weight	29
4	PIN AND SIGNAL DESCRIPTIONS	29

4.1	3.3V 1.8" SSD Signal and Power Description Tables	29
4.2	Hot Plug Support	30
5	COMMAND SETS	30
5.1	ATA Commands	31
5.1.1	48-Bit Address Command Set	34
5.1.2	ATA General Feature Command Set	35
5.1.3	Device Configuration Overlay Command Set	35
5.1.4	General Purpose Log Command Set	35
5.1.5	Host Protected Area Command Set	35
5.1.6	Power Management Command Set	36
5.1.7	Security Mode Feature Set	36
5.1.8	S.M.A.R.T. Support	36
5.1.9	S.M.A.R.T. Attributes	39
5.1.10	Attribute Sector	56
5.1.11	Threshold Sector	56
5.1.12	S.M.A.R.T. Command Transport (SCT)	57
5.2	SATA Commands	57
5.2.1	Native Command Queuing (NCQ)	57
6	CERTIFICATIONS AND COMPLIANCE	58
7	REFERENCES	59
8	GLOSSARY	60

Table of Tables

Table 1-1: Element SSD Features	12
Table 2-1: Capacity and LBA Count	15
Table 2-2: Maximum Sustained Read and Write: MB/sec and IOPS	17
Table 2-3: Timing Specifications	18
Table 2-4: STANDBY IMMEDIATE Timing	18
Table 2-5: Absolute Maximum Ratings for 3.3V SSD's	19
Table 2-6: 3.3V Operating Voltage	19
Table 2-7: Current, 3.3V input	19
Table 2-8: Power Consumption at 3.3V	20
Table 2-9: Temperature and Altitude Related Specifications	20
Table 2-10: Shock and Vibration Specifications	21
Table 2-11: Electromagnetic Compatibility Specifications	21
Table 2-12: Reliability Specifications	22
Table 2-13: Element SSD Secure Erase Commands	26
Table 2-14: Military Secure Erase / Sanitize Routines	27
Table 3-1: Physical Dimensions	28
Table 4-1: 1.8" SSD Serial ATA Connector Pin Signal Definitions	29

Table 4-2: 1.8" SSD Serial ATA Power Pin Definitions	29
Table 5-1: ATA Feature Set	30
Table 5-2: ATA Commands	31
Table 5-3: S.M.A.R.T. Command Set	37
Table 5-4: Supported S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE Subcommands	38
Table 5-5: Baseline S.M.A.R.T. Attribute Summary	39
Table 5-6: Baseline S.M.A.R.T. Attribute Details	43
Table 5-7: S.M.A.R.T. Attribute Default Threshold Values & Clear Conditions	55
Table 5-8: S.M.A.R.T. Attribute Data Structure	56
Table 5-9: S.M.A.R.T. Threshold Data Structure	57
Table 6-1: Device Certifications	58

Table of Figures

Figure 1-1: High-Level Block Diagram for Client /Industrial Series	14
Figure 1-2: High-Level Block Diagram for Enterprise Series	14
Figure 3-1: 1.8" SSD Dimensions	28
Figure 5-1: S.M.A.R.T. ECC and RAISE Error Summary	42
Figure 5-2: S.M.A.R.T. ECC and RAISE Error Summary for Industrial versions of VRFS1xGA and VRFS1xGK	42

1 Introduction

1.1 Features

Viking's rugged industrial designed SSD's offer the highest flash storage reliability and performance in harsh environments such as shock, vibration, humidity, altitude, ESD, and extreme temperatures. Viking SSD's meet JEDEC JESD22 standards and pass numerous qualifications including MIL-STDs and NEBS.

Viking can also provide specialized services to OEMs designing customized hardware and systems by offering:

- Locked BOM control with customer product change notification (PCN)
- Pre-installed software, custom software imaging and ID strings
- Custom packaging and labeling
- Comprehensive supply-chain management
- Customer specified testing
- 30k volt ESD protection
- Conformal coating
- Localized Field Application Engineering for complete pre and post sale technical support

Table 1-1: Element SSD Features

The Element SSD Processor delivers the following features:

Feature	VRFS1xGA VRFS1xGJ	VRFS1xGF	VRFS1xGK VRFS1xGM	Industrial Versions
Best in class sequential and random Read/Write performance		•	•	•
Seamless SATA Revision 2.x interface support for SATA up to 3Gbps)	•	•	•	•
Seamless SATA Revision 3.x interface support for SATA up to 6Gbps)		•	•	VRFS1xGK only
Power hold-up circuit technology ensures no data loss resulting from an unexpected power loss and is supported for industrial temperatures	•	•		•
PFAIL/DHARD signaling with the host				
Support for ONFi and Toggle Mode NAND	VRFS1xGJ only	•	•	VRFS1xGK only
Low Power Mode	VRFS1xGJ only	•	•	VRFS1xGK only
Patented architecture for SSD longevity, reliability and data integrity	•	•	•	•
Supports Native Command Queuing (NCQ) to 32 commands	•	•	•	•
Native support for 512 and non-512 host LBA sizes		•	•	VRFS1xGK only
Automatic Trim Command support	•	•	•	•
Compatible with all major SLC, eMLC and MLC NAND flash technologies	•	•	•	•
Protection against catastrophic flash page and block failures	•	•	•	•
AES-128 encryption in CTR mode	•	•		•
AES-256 encryption in XTS mode		•	•	VRFS1xGK only
S.M.A.R.T. command transport (SCT) technology	•	•	•	•
Superior wear-leveling algorithm	•	•	•	•
Intelligent flash memory block management and read disturb management	•	•	•	•
Efficient error recovery	•	•	•	•
Power-throttling support	•	•	•	•
Customer selectable Drive Life	•	•	•	•

Feature	VRFS1xGA VRFS1xGJ	VRFS1xGF	VRFS1xGK VRFS1xGM	Industrial Versions
Protection (Factory setting is 3 years)				
Thermal sensing energy management	•	•	•	•
Stainless steel housing for ruggedness, low EMI/ESD, and thermal management	•	•	•	•
RoHS and WEEE compliant	•	•	•	•

1.2 Block Diagram

Figure 1-1: High-Level Block Diagram for Client /Industrial Series

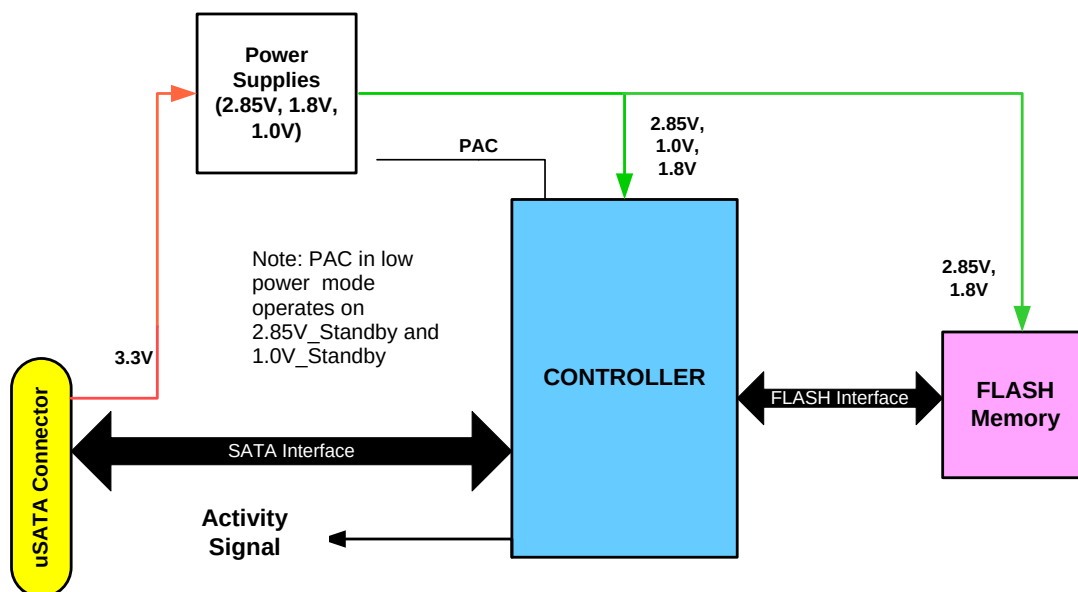
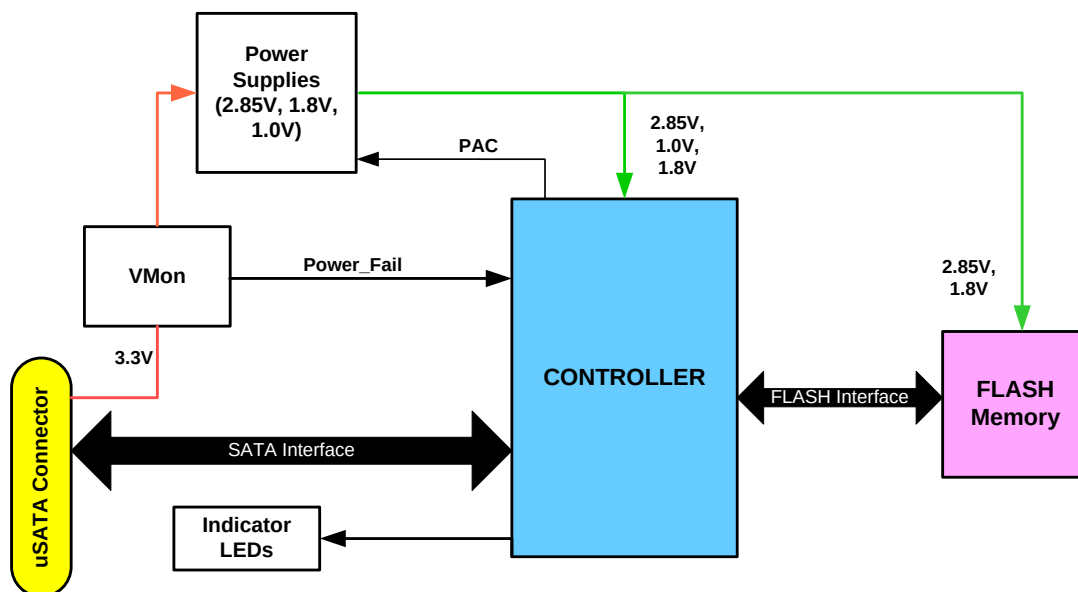


Figure 1-2: High-Level Block Diagram for Enterprise Series



1.3 SATA Interface for VRFS1xGA, VRFS1xGJ

- The Serial ATA (SATA) interface is compliant with the SATA IO Serial ATA specification, Revision 2.6 that supports SATA up to 3Gbps.
- The SATA interface connects the host computer to the SSD subsystem.
- The SATA interface runs at a maximum speed of 3 Gbps (Gigabits per second). If the host computer is unable to negotiate a speed of 3 Gbps, the SATA interface automatically renegotiates to a speed of 1.5 Gbps.

1.4 SATA Interface for VRFS1xGF, VRFS1xGK, VRFS1xGM

- The Serial ATA (SATA) interface is compliant with the SATA IO Serial ATA specification, revision 3.x that support SATA up to 6 Gbps.
- The SATA interface connects the host computer to the SSD subsystem.
- The SATA interface runs at a maximum speed of 6.Gbps (Gigabits per second). If the host computer is unable to negotiate a speed of 6 Gbps, the SATA interface automatically renegotiates to a speed of 3 or 1.5 Gbps.

For a list of supported commands and other specifics, please see Chapter 5.

2 Product Specifications

2.1 Capacity-LBA

Table 2-1: Capacity and LBA Count

CAPACITY RAW	CAPACITY USER	512_LBA_COUNT
8	6	11,718,750
8	8	15,625,000
16	16	31,277,232
16	12	23,463,216
16	14	27,370,224
16	12.5	24,439,968
24	24	46,905,264
24	22	42,998,256
24	18.75	36,649,368
32	32	62,533,296
32	25	48,858,768
32	30	58,626,288
48	48	93,789,360
48	40	78,161,328
48	45	87,928,848
48	37.5	73,277,568
64	64	125,045,424
64	55	107,463,888
64	60	117,231,408

CAPACITY RAW	CAPACITY USER	512_LBA_COUNT
64	50	97,696,368
96	80	156,301,488
96	90	175,836,528
96	96	187,557,552
96	75	146,533,968
128	120	234,441,648
128	128	250,069,680
128	121	236,395,152
128	100	195,371,568
192	160	312,581,808
192	180	351,651,888
192	192	375,093,936
192	150	293,046,768
256	240	468,862,128
256	256	500,118,192
256	251	490,350,672
256	225	439,559,568
256	200	390,721,968
384	360	703,282,608
384	384	750,166,704
384	335	654,445,008
384	300	586,072,368
512	480	937,703,088
512	512	1,000,215,216
512	450	878,977,968
512	400	781,422,768

2.2 Performance

Maximum SSD performance can be achieved for certain workloads by:

- Initiating read and write transfers for random accesses with small block sizes of 4k bytes to optimize IOP's performance for applications such as databases, OLTP etc.
- Initiating read and write transfers for sequential accesses with large blocks (128k or larger) to optimize performance toward throughput (MBps) for applications such as video streaming, data acquisition etc.
- Issuing transfers at starting LBA's that align the access on 4k boundaries:
 - o Minimizes or eliminates internal Read-Modify-Write operations
 - o Align on 4k boundaries is optimal for SSD capacities up to 256 GB
 - o For SSD capacities greater than 256 GB, aligning on 8k boundaries is optimal

- Avoid mixing NCQ and non-NCQ commands

Table 2-2: Maximum Sustained Read and Write: MB/sec and IOPS

Access Type	VRFS1xGA VRFS1xGJ	VRFS1xGK VRFS1xGM	VRFS1xGF VRFS1xGN	Units
Sequential Read, 128K block size	Up to 260	Up to 500	Up to 520	MB/s
Sequential Write, 128K block size	Up to 260	Up to 500	Up to 520	MB/s
Random Read, 4K block size	Up to 30,000	Up to 60,000	Up to 60,000	IOPS
Random Write, 4K block size	Up to 30,000	Up to 20,000	Up to 60,000	IOPS

Notes:

1. Performance measured after SSD preconditioning
2. Tested with IOMeter 08 and queue depth (QD) set to 32.
3. Write Cache enabled.
4. Random IOPS (Input/Output Operations per Second) cover the entire range of legal logical block addresses (LBA's). Measurements are performed on a full drive (all LBA's have valid content).
5. Performance may vary by NAND type and host.
6. Refer to Application Note AN0006 for Viking SSD Benchmarking Methodology.

2.3 Timing

Table 2-3: Timing Specifications

Type	Average Latency (ms) Write Cache Enabled
Power On to Ready (POR)	<1
Reset to Ready	<2
Command to DRQ	<1
Time to Erase (ATA Secure Erase)	4 second (entire drive)

Notes:

1. Based on MLC NAND
2. Device measured using IOMETER 08, Queue depth set to 32 for NCQ
3. Sector Read/Write latency measured up to 4K block size (512B/sector = 1 Block), random access
4. Sequential IOPS cover the entire range of valid logical block addresses (LBA's). Measurements are performed on a full drive (all LBA's have valid content)

2.3.1 STANDBY IMMEDIATE Command

The Power On to Ready time assumes a proper shutdown (power removal preceded by STANDBY IMMEDIATE command. A STANDBY IMMEDIATE before power down always performs a graceful shutdown and does not require the use of the hold-up circuit. Note that SMART attribute 174 "Unexpected Power Loss" records the number of non-graceful power cycle events.

The timings for when a STANDBY IMMEDIATE is issued to when it is completed are shown in the table below.

Table 2-4: STANDBY IMMEDIATE Timing

Power Cycle Endurance	Min	Max	Unit
STANDBY IMMEDIATE to WE completed	-	40	ms

2.4 Electrical Characteristics

2.4.1 Absolute Maximum Ratings

Table 2-5: Absolute Maximum Ratings for 3.3V SSD's

Values shown are stress ratings only. Functional operation outside normal operating values is not implied. Extended exposure to absolute maximum ratings may affect reliability.

Description	Min	Max	Unit
Maximum Voltage Range for Vin	-0.3	4.0	V
Maximum Temperature Range	-40	+85	c

2.4.2 Supply Voltage

1.8" SSD's operate at 3.3V.

Table 2-6: 3.3V Operating Voltage

Description	Min	Max	Unit
Operating Voltage for 3.3 V (+/- 5%)	3.14	3.47	V

2.4.3 Supply Current

Table 2-7: Current, 3.3V input

	Client — 480GB		Enterprise — 400GB	
	6Gbps	3Gbps	6Gbps	3Gbps
	Current (mA)	Current (mA)	Current (mA)	Current (mA)
Write	1548	1385	1730	1467
Read	939	682	1133	824
Idle	294	258	621	591

Notes:

1. Values based IOMeter 06: 100% Sequential, 256K Transfer, Q Depth: 32. Temperature: 25C

2.4.4 Power Consumption

All onboard power requirements of the Element SSD are derived from the SATA 3.3V input rail.

Table 2-8: Power Consumption at 3.3V

	Client — 480GB		Enterprise — 400GB	
	6Gbps	3Gbps	6Gbps	3Gbps
	RMS Power (W)	RMS Power (W)	RMS Power (W)	RMS Power (W)
Write	5.11	4.57	5.71	4.84
Read	3.10	2.25	3.74	2.72
Idle	0.97	0.85	2.05	1.95

Notes:

1. Values based IOMeter 06: 100% Sequential, 256K Transfer, Q Depth: 32. Temperature: 25C

2.5 Environmental Conditions

2.5.1 Temperature and Altitude

Table 2-9: Temperature and Altitude Related Specifications

Condition	Operating	Shipping	Storage
Commercial Temperature - Ambient	0 to 70°C (32 to 158° F)	-40 to 100°C (-40 to 212° F)	-40 to 100°C (-40 to 212° F)
Industrial Temperature² - Ambient	-40 to 85°C (-40 to 185° F)	-40 to 100°C (-40 to 212° F)	-40 to 100°C (-40 to 212° F)
Humidity (non-condensing)	10% to 80%	5% to 95%	5% to 95%
Max Temperature Gradient	20°C/Hour (36°F/Hour)	n/a	n/a
Altitude⁴	-304.8 to 24,384 m (-1,000 to 80,000 ft)	-304.8 to 24,384 m (-1,000 to 80,000 ft)	-304.8 to 24,384m (-1,000 to 80,000 ft)
Storage Time	n/a	n/a	1 year ³

Notes:

1. RFU
2. Not available on VRFS1xGF series
3. Also refer to data retention specifications.
4. Max altitude specification for xxGAxx and xxGBxx part numbers is limited to 3048 m (10,000 ft)

2.5.2 Shock and Vibration

Table 2-10: Shock and Vibration Specifications

	Mode	
Shock ¹ Operating and non-Operating	MIL STD-810F, section 516.5	50g 11ms, 3 Axis, Half Sine, Positive and Negative
Vibration ¹ Operating and non-Operating	MIL STD-810F, section 514.5	10~1000Hz: 0.04g ² /Hz 3 Axis 1000~2000Hz: 6db/oct 3 Axis

Notes:

1. Shock and vibration specifications assume that the SSD is latched securely. Stimulus may be applied in the X, Y, or Z axis.

2.5.3 Electromagnetic Compatibility

Electromagnetic Compatibility tests assume the SSD is properly installed in the representative host system. The drive will operate properly without errors or degradation in performance when subjected to environments defined in the following table:

Table 2-11: Electromagnetic Compatibility Specifications

Test	Description	Performance Criteria	Reference Standard
Electrostatic discharge	Contact, HCP, VCP: ±8 kV; Air: ±15 kV	B	EN 61000-4-2: 1995
Radiated RF Immunity	80 to 6,000 MHz, 3 V/m, 80% AM with 1 kHz sine	A	EN 61000-4-3: 2002 ENV 50204: 1995
Surge Immunity	±1 kV differential, ±2 kV common, AC mains	B	EN 61000-4-5: 1995
Conducted RF Immunity	150 kHz to 80 MHz, 3 Vrms, 80% AM with 1 kHz sine	A	EN 61000-4-6: 1996

Notes:

1. **Performance Criteria A of CE Spec** = The device shall continue to operate as intended, i.e., normal unit operation with no degradation of performance.
2. **Performance Criteria B of CE Spec** = The device shall continue to operate as intended after completion of the test. However, during the test, some function degradation of performance is allowed as long as there is no data loss operator intervention to restore device function.
3. Electrostatic discharge applied to drive enclosure.

2.6 Reliability

Table 2-12: Reliability Specifications

Parameter	Value
Nonrecoverable read errors (UBER) ¹	<1 sector in 10 ¹⁷ bits read, max
Mean Time Between Failures (MTBF) ²	3,000,000 hours
Power On/Off Cycles ³	50,000 cycles
Read Endurance	Unlimited
Write or Erase Endurance ⁴	(specified by the flash component)
Global wear-leveling	~ 2% between least worn and most worn cell
Data retention	See Note 5

Notes:

1. Uncorrectable Bit Error rate (UBER) will not exceed one sector in the specified number of bits read. In the extremely unlikely event of a non-recoverable read error, the drive will report it as a read failure to the host; the sector in error is considered corrupt and is not returned to the host.
2. MTBF is calculated based on a Part Stress Analysis. It assumes nominal voltage, with all other parameters within specified range. Telcordia method SR-332, component FIT rate at 55°C.
3. Power On/Off Cycles defined as power being removed from the drive, and then restored. Note that host systems and drive enclosures may remove power from the drive for reasons other than a system shutdown.
4. SLC NAND has a higher write/erase cell endurance than MLC NAND; varies by NAND component.
5. 10 years for P-E cycle counts < 10% of NAND spec and 1 year for max-spec P-E cycle counts per JEDEC-STD-JESD47) Refer to Viking Application Note AN0011 – Flash Data Retention

2.6.1 Data, MetaData, and Firmware Code Protection

Element SSD implements data protection throughout its data path. Protection techniques include:

- Data ECC Algorithms
- Datapath CRC Error Detection
- RAISE™ Data Protection Against Catastrophic Flash Page/Block Failure

2.6.1.1 DATA ECC Algorithms

The following data error correction is provided:

- For Flash memory devices providing 128 bytes of redundancy per 4k of data (normally this is SLC Flash)
 - o 16 bytes of redundancy applied to 512 bytes of data
 - o Up to seven 9-bit symbols (up to 63 bits if contiguous) correctable
- For Flash memory devices providing 218 or more bytes of redundancy per 4k of data (normally this is MLC Flash)
 - o 27 bytes of redundancy applied to 512 bytes of data
 - o Up to twelve 9-bit symbols (up to 108 bits if contiguous) correctable

2.6.1.2 Data Path CRC Error Detection

CRC error detection is applied against data along internal data paths. CRC detection uses a 32-bit checksum (CRC32) to protect data along all internal data paths to correct silent errors not detected by other schemes.

2.6.1.3 RAISE™ Data Protection Against Catastrophic Flash Page/Block Failure

Element SSD implements proprietary R.A.I.S.E.™ (Redundant Array of Independent Silicon Elements) data protection, to overcome the probabilistic risk of page or block failure inherent in all Flash memory technology.

Flash technology can exhibit a finite probability that a block or page will fail within the rated Program-Erase (P-E) cycle count lifetime of the Flash device. While this probability may appear tolerable for a given application, note that it is for a particular Flash die. For an SSD incorporating up to 128 Flash die, the additive probability of this phenomenon can reveal measurable risk to the SSD over its multi-year lifetime.

Element SSD technology addresses this risk. In the event of a catastrophic failure of an entire Flash page or Flash block, RAISE™ off-line protection rebuilds the data in the failed page or block and relocates it elsewhere in the Flash array. Performance during recovery is impacted, but after recovery is complete, Element SSD returns to full performance and full functionality. The performance impact period is only the amount of time required to rebuild and relocate the page or block data, and to map out the problematic Flash block.

In contrast to other SSD Flash controllers, Element SSD with RAISE™ technology uniquely, reliably and seamlessly overcomes these catastrophic data loss risks with only temporary impact to throughput and latency and no impact to power consumption. In a RAID drive array application, Element SSD can auto-rebuild data locally, without passing the problem upstream to the system level and without incurring the associated significant system rebuild hit. The difference in impact between a standard approach and Element SSD with RAISE™ approach is significant. Additionally, following recovery from a page failure or block failure, Element SSD is fully functional and fully reliable, whereas a page-failed or block-failed drive recovered by system RAID must be immediately replaced.

2.6.1.4 Firmware Code Protection

Firmware requires special attention to ensure the code is execution-worthy. For this reason, firmware is stored in multiple redundant images in the Flash array. Image checksums are compared between all stored copies to ensure identical

Manual	1/2/2014
PSFS1XXXXGXXXX	Viking Technology
Revision B7	Page 23 of 60

code. Any image not corroborated by at least one other image is discarded. In this way a reliable firmware image is always chosen on boot-up for execution.

If a firmware image is discarded, a new redundant image is created from the good images to ensure original levels of protection.

Firmware images are also protected in Flash memory and during fetch by the maximum ECC correction power, and by RAISE™ correction technology.

2.6.2 Intelligent Read Disturb Management

Flash memory is primarily at risk from writes and erasures. However, reads also affect data longevity. Excessive reads of Flash memory cells induce inter-cell voltage shift, although the effect not as accelerated as write-induced cell damage. The degradation occurs in data stored in nearby cells, rather than in the cell being read. Read-induced data degradation is called “Read Disturb.”

The controller provides read operation management to overcome Flash Memory “Read Disturb” concerns by ensuring that data integrity is not impacted by multiple reads of the same Flash Memory address. It tracks reads and automatically and seamlessly recovers and refreshes data in proximity before that data is negatively impacted. Its superior throughput and latency performance, delivered over the life of the drive, is not diminished by this process and the expected data retention capability is assured throughout the warranted life of the SSD.

2.6.3 Intelligent Write Operation Management

The controller makes data location/relocation decisions which greatly increase the life of the SSD.

2.6.3.1 Sophisticated Wear-Leveling

Wear leveling refers to the practice of equalizing the impact of write and erase operations over the larger pool of Flash memory blocks. Industry-standard wear leveling techniques focus on conventional schemes that attempt to equalize writes and erases across blocks. While on the surface this appears to be a reasonable approach, it is clear that it assumes all blocks will “wear” equally when written or erased. This is far from the truth. The NAND processor takes much more into account. It measures a variety of parameters to determine the actual wear of blocks during P-E cycles, to determine which blocks are impacted more by erasures and writes over time. That is, it determines actual cell wear, not simply assumed wear normalized to write/erase events. The controller employs this information in its superior wear-leveling algorithm along with its ongoing record of writes and erasures, to ensure each block is impacted by P-E cycles no

Manual	1/2/2014
PSFS1XXXXGXXXX	Viking Technology
Revision B7	Page 24 of 60

more than the average. The result is an SSD that is far more reliable across its full capacity and over a far greater length of time. The controller uses both static and dynamic wear-leveling algorithms to globally manage cell degradation to approximately 2% between least worn and most worn cells or to the value specified in the S.M.A.R.T Wear Range Delta command (ID=177, Opcode=0xB1)

2.6.3.2 Write Operation Reduction

The controller uses intelligent algorithms to minimize P-E cycles through aggregation, virtualization, and difference processing. It is uniquely effective in reducing the wear and maintaining the reliability of the overall pool of Flash memory blocks by intelligently minimizes re-writes of identical data, to maximize the effectiveness of the wear-leveling process.

2.7 Data Security

Viking Element SSD's are self-encrypting drives (SED), with a bulk data encryption feature that provides automatic hardware-based data security and enhanced secure erase capability.

A self-encrypting drive, scrambles data using a data encryption key as it is written to the drive and then descrambles it with the key as it is retrieved. This gives the user the highest level of data protection available and provides a fast erase simply by deleting the encryption key, eliminating the need for time consuming data-overwrite. Data on the drive is instantly rendered unreadable.

The Element SSD supports AES-128 encryption (in CTR mode) and ATA Secure Erase features to protect sensitive data. The VRFS1xGF and VRFS1xGK series also supports AES-256 encryption (in XTS mode) and TCG security enhancements.

The ATA Security Erase Unit command, which is usually password protected, will erase:

- All map data
- The encryption key (All data in flash is scrambled and unrecoverable)

and the resulting condition of the drive after an ATA Security Erase will be:

- Any reads to the drive will respond with zero for every LBA
- Any writes to the drive will act as if the drive has nothing; a T0 state.

If the flash memory was directly probed, some scrambled data might be retrievable, but there would be no way to decode it without the encryption key.

Manual	1/2/2014
PSFS1XXXXGXXXX	Viking Technology
Revision B7	Page 25 of 60

2.7.1 Secure Erase Support

In the following table are the supported Secure Erase Commands for the Element SSD.

Table 2-13: Element SSD Secure Erase Commands

Command	Action	SSD Code ¹	Time to Execute
Secure Erase	• Erase all map data • Erase encryption key • Erase all LBAs • Erase SMART attributes, logs, thresholds • Reset/Regenerate a new AES key	Note 1	< 4 seconds
Secure Erase with Flash Erase	Secure Erase actions plus the erasure of all encrypted data and blocks in flash memory	Note 1	~1 second/GB

Notes:

1. Enabled in firmware at the time of manufacture and prior to shipping from the factory

There are two primary reasons for performing a Secure Erase on an SSD. The first and perhaps the most important is to remove ultra-sensitive data from the drive to prevent any access and ensure the privacy of information previously stored in the flash. This aspect of the secure erase is often required by some military or government agencies.

The second reason for a Secure Erase is to initialize the drive to a known starting point for benchmarking purposes or to increase performance and/or capacity by eliminating any preconditioning.

Unlike the ATA Security Erase Unit command which only erases the map data and the encryption key for the encrypted data in flash memory, the Secure Erase command will also:

- Erase all map data (and checks the drive to ensure map loss is persistent)
- Erase encryption key (All data in flash is scrambled and unrecoverable)
- Erase all LBAs (0 to MAX) in DEVICE CONFIGURATION IDENTIFY
- Erase SMART Attributes 1, 13, 195, 199, 201, 204 (clear by power cycle)
- Erase SMART Logs
- Erase SMART Thresholds (and return to default)
- Reset and regenerate a new AES key to apply to all data

In less than 4 seconds after a Secure Erase command, scrambled encrypted data cannot be located or retrieved.

The SSD also has an optional Cryptographic Erase plus Physical Flash Erase command where in addition to a Secure Erase, all encrypted, unreadable data and all Flash blocks (excluding FW blocks) are erased. Persistent drive life data is rewritten to the flash blocks after erase. The operation time for a Cryptographic Erase with Physical Flash Erase, scrambled encrypted data is ~ 1 second/GByte.

2.7.1.1 Military Secure Erase / Sanitization

Many government and military organizations such as NIST/NSA define their own standard and procedures for performing a Military Secure Erase which overwrite different patterns to sanitize the flash media. Some of the more common military or government purge routines are defined in the following table and the data security features of the drive comply with Department of Defense (DoD) and US military data security standards.

Table 2-14: Military Secure Erase / Sanitize Routines

Standard	Action	SSD Code ¹
NSA/CSS 9-12	Erase and overwrite all locations with a known unclassified pattern. Verify the overwrite procedure by randomly rereading the overwritten information to confirm that only the known pattern can be recovered.	Note 1
NSA/CSS 130-2	Erase the media and overwrite with random data 2 times, then erase and overwrite with a character	Note 1
DoD5220.22-M NISPOM	Erase the media and overwrite with single character, then erase again	Note 1
DoD5220.22-M NISPOM Sup 1	Erase the media and overwrite with single character, then erase again and overwrite with single character, then erase again and overwrite with random character then erase again	Note 1
USA Army 380-19	Erase the media and overwrite with random data, erase and overwrite with a character, then erase and overwrite with complement of the character	Note 1
Navy NAVSO P-5239-26	Erase the media and overwrite with random data, then erase again	Note 1
Air Force AFSSI 5020	Erase the media and overwrite with pattern, repeat 3 times	Note 1
IRIG 106-2007 IRIG 106-07, Ch. 10.8	Erase the media, overwrite with 0x55, erase, overwrite with 0xAA, and then erase again. Then fill the drive with a repeating string of Secure Erase.	N/A

Notes:

1. Enabled in firmware at the time of manufacture and prior to shipping from the factory
2. NSA/CSS 9-12 is the factory default unless otherwise requested.

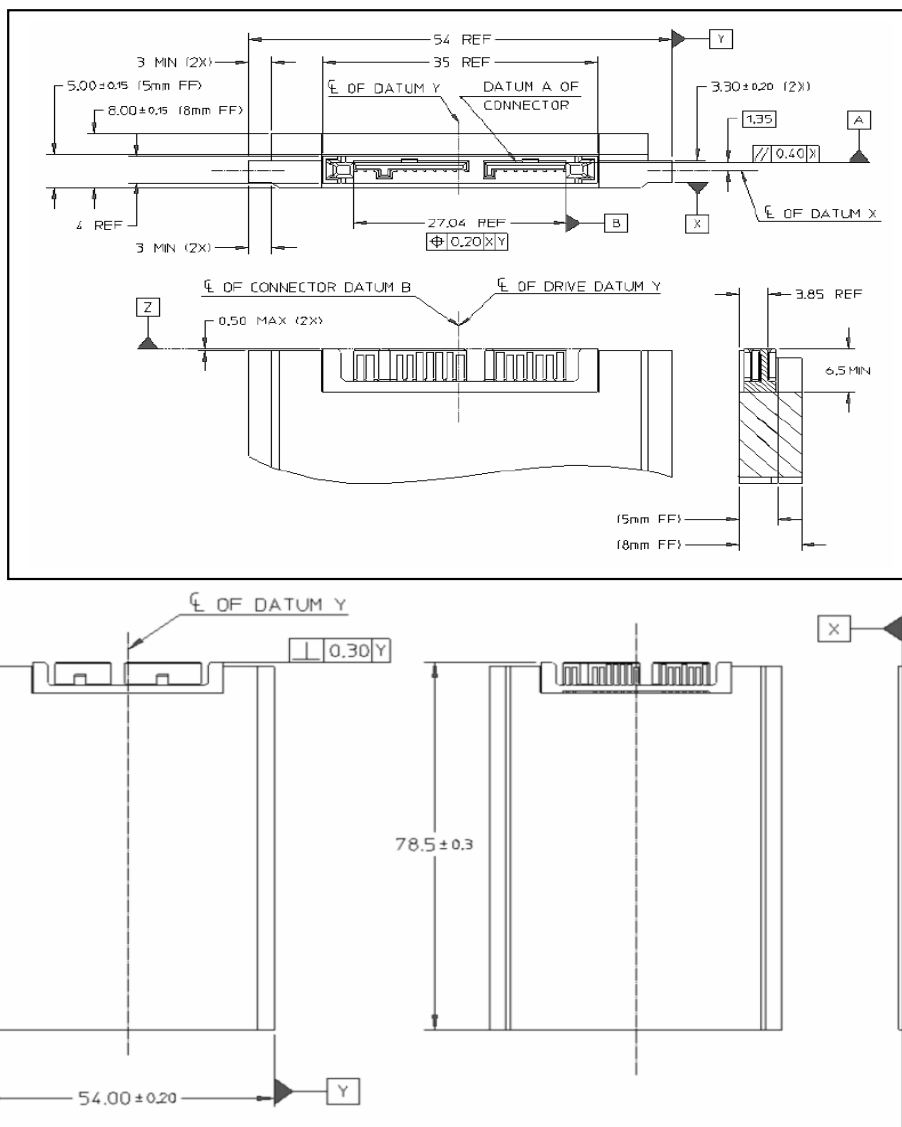
3 Mechanical Information

3.1 Element SSD Physical Dimensions

Table 3-1: Physical Dimensions

Dimensions	VRFS1x	Units
Height / Thickness	5.0 +/- 0.15	mm
Width	54 +/- 0.2	mm
Length	78.5 +/- 0.3	mm

Figure 3-1: 1.8" SSD Dimensions



Notes: All dimensions are in millimeters.

3.2 Element SSD Weight

The weight of the enterprise 1.8" SSD is approximately 50 grams. The weight of the client 1.8" SSD is approximately 30 grams.

4 Pin and Signal Descriptions

4.1 3.3V 1.8" SSD Signal and Power Description Tables

Table 4-1: 1.8" SSD Serial ATA Connector Pin Signal Definitions

Pin	Function	Definition	Mating Order
S1	SGND_1	Signal Ground	2nd
S2	RX+ on SSD, TX+ on Host	Differential Signal	
S3	RX- on SSD, TX- on Host	Differential Signal	
S4	SGND_2	Signal Ground	2nd
S5	TX- on SSD, RX- on Host	Differential Signal	
S6	TX+ on SSD, RX+ on Host	Differential Signal	
S7	SGND_3	Signal Ground	2nd

Notes:

1. Key and spacing separate signal and power segments.
2. Pin locations and layout are consistent with SATA specification.

Table 4-2: 1.8" SSD Serial ATA Power Pin Definitions

Pin	Function	Definition	Mating Order
P1	3.3V_1	3.3 V Power	2nd
P2	3.3V_2	3.3 V Power, Pre-charge	1st
P3	GND_1	Ground	1st
P4	GND_2	Ground	1st
P5	5V_1	Not connected (open circuit)	
P6	5V_2	Not connected (open circuit)	
P7	LED	Activity signal	2nd
KEY	KEY	KEY	NC
P8	Optional	Vendor specific	2nd
P9	Optional	Vendor specific	2nd

4.2 Hot Plug Support

Hot Plug insertion and removal are supported in the presence of a proper connector and appropriate operating system (OS) support as described in the SATA 2.6 and SATA 3 specification. This product supports Asynchronous Signal Recovery and will issue an unsolicited COMINIT when first mated with a powered connector to guarantee reliable detection by a host system without hardware device detection.

5 Command Sets

The Element SSD complies with ATA-8. All mandatory and many optional commands and features are supported. The tables below summarize the supported ATA feature set and commands.

Table 5-1: ATA Feature Set

Feature Set	ATA-8 REF	Support	
		ATA Device	Element SSD
General feature set	4.2	M	YES
PACKET feature set	4.3	P	NO
48-Bit Address feature set	4.4	O	YES
Advanced Power Management (APM) feature set	4.5	O	NO
Automatic Acoustic Management (AAM) feature set	4.6	O	NO
CompactFlash Association (CFA) feature set	4.7	N	NO
Device Configuration Overlay (DCO) feature set	4.8	O	YES
Free-fall Control feature set	4.9	O	NO
General Purpose Logging (GPL) feature set	4.10	O	YES
Host Protected Area (HPA) feature set	4.11	O	YES
Long Logical Sector (LLS) feature set	4.12	O	NO
Long Physical Sector (LPS) feature set	4.13	O	NO
Media Card Pass Through Command feature set	4.14	N	NO
Native Command Queuing (NCQ) feature set	4.15	O	YES
NV Cache feature set	4.16	O	NO
NV Cache Power Management feature set	4.17	O	NO
Power Management feature set	4.18	M	YES
Power-Up In Standby (PUIS) feature set	4.19	O	YES
Security feature set	4.20	O	YES
S.M.A.R.T. feature set	4.21	O	YES
Software Settings Preservation (SSP) feature set	4.22	O	YES

Feature Set	ATA-8 REF	Support	
		ATA Device	Element SSD
Streaming feature set	4.23	O	NO
Tagged Command Queuing (TCQ) feature set	4.24	O	NO
Trusted Computing feature set	4.25	O	NO
Write-Read-Verify feature set	4.26	O	NO
Key: M – Mandatory, O – Optional, P – Prohibited, N – Not defined, YES – Supported, NO – Not Supported			

5.1 ATA Commands

Table 5-2: ATA Commands

ATA-8 REF	Commands	ATA-8	Sup	Key Word Option	Feature Set	OP
7.2	CFA ERASE SECTORS	N	NO	CfaEraseSec, CFES	CFA	C0h
7.3	CFA REQUEST EXTENDED ERROR CODE	O	NO	CfaReqErr, CFRE	CFA	03h
7.4	CFA TRANSLATE SECTOR	O	NO	CfaTransSec, CFTS	CFA	87h
7.5	CFA WRITE MULTIPLE WITHOUT ERASE	O	NO	CfaWrMul, CFWM	CFA	CDh
7.6	CFA WRITE SECTOR(S) WITHOUT ERASE	O	NO	CfaWrSec, CFWS	CFA	38h
7.7	CHECK MEDIA CARD TYPE	O	NO	ChkMedType, CHMT	Media Card	D1h
7.8	CHECK POWER MODE	M	YES	ChkPwrMode, CKPW, CHPW	Power Manage	E5h
7.9	CONFIGURE STREAM	O	NO	CfgStr, CFST	Streaming	51h
7.10.2	DEVICE CONFIGURATION FREEZE LOCK	O	YES	DevCfgFrzLock, DCOF, DCFL	DCO	B1h/C1h
7.10.3	DEVICE CONFIGURATION IDENTIFY	O	YES	DevCfgIdfy, DCOI, DCFI	DCO	B1h/C2h
7.10.4	DEVICE CONFIGURATION RESTORE	O	YES	DevCfgRestore, DCOR, DEFR	DCO	B1h/C0h
7.10.5	DEVICE CONFIGURATION SET	O	YES	DevCfgSet, DCOS, DCFS	DCO	B1h/C3h
7.11	DEVICE RESET	N	NO	DevRst, DRST	Packet	08h
7.12	DOWNLOAD MICROCODE	O	YES	Download, DNLD	General	92h
7.13	EXECUTE DEVICE DIAGNOSTIC	M	YES	Diagnose, DIAG	General	90h
7.14	FLUSH CACHE	M	YES	FlushCache, FLSH	General	E7h
7.15	FLUSH CACHE EXT	M	YES	FlushCacheEx, FLSE, FLEX	48-bit Address	EAh
7.16	IDENTIFY DEVICE	M	YES	Identify, IDFY	General	ECh
7.17	IDENTIFY PACKET DEVICE	N	NO	IdfyPktDev, IDPD	Packet	A1h
7.18	IDLE	M	YES	IDLE	Power Manage	E3h
7.19	IDLE IMMEDIATE	M	YES	IDLI	Power Manage	E1h
-	IDLE/UNLOAD IMMEDIATE	O	YES			E1h-41h

ATA-8 REF	Commands	ATA-8	Sup	Key Word Option	Feature Set	OP
-	INITIALIZE DRIVE PARAMETERS	M	YES			91h
7.20.3	ADD LBA(S) TO NV CACHE PINNED SET	O	NO		NV Cache	B6h/10h
7.20.4	FLUSH NV CACHE	O	NO		NV Cache	B6h/14h
7.20.5	NV CACHE DISABLE	O	NO		NV Cache	B6h/16h
7.20.6	NV CACHE ENABLE	O	NO		NV Cache	B6h/15h
7.20.7	QUERY NV CACHE MISSES	O	NO		NV Cache	BRh/13h
7.20.8	QUERY NV CACHED PINNED SET	O	NO		NV Cache	B6h/12h
7.20.9	REMOVE LBA(S) FROM CACHED PINNED SET	O	NO		NV Cache	B6h/11h
7.20.10	RETURN FROM NV CACHE POWER MODE	O	NO		NV Cache	B6h/01h
7.20.11	SET NV CACHE POWER MODE	O	NO		NV Cache	B6h/00h
7.21	NOP	O	YES	NOP	General	00h
7.22	PACKET	O	NO	Packet, PAKT	Packet	A0h
7.23	READ BUFFER	O	YES	RdBuf, RBUF	General	E4H
7.24	READ DMA	M	YES	RdDma, RDMA	General	C8h
7.25	READ DMA EXT	M	YES	RdDmaEx, RDMX	48-bit Address	25h
7.26	READ DMA QUEUED	O	NO	RdDmaQ, RDMQ	TCQ	C7h
7.27	READ DMA QUEUED EXT	O	NO	RdDmaQEx, RDQX	TCQ	26h
-	READ DMA (w/o retry)	Obs	YES			C9h
7.28	READ FPDMA QUEUED	M	YES	RFPDMAQ, RDMA_NCQ	NCQ	60h
7.29	READ LOG EXT	M	YES	RdLogEx, RLEX	GPL	2Fh
7.30	READ LOG DMA EXT	O	YES		48-bit Address	47h
7.31	READ MULTIPLE	M	YES	RdMul, RMUL	General	C4h
7.32	READ MULTIPLE EXT	M	YES	RdMulEx, RDME, RMEX	48-bit Address	29h
7.33	READ NATIVE MAX ADDRESS	M	YES	RdNativeMax, RNMA	HPA	F8h
7.34	READ NATIVE MAX ADDRESS EXT	M	YES	RdNativeMaxEx, RNME	HPA	27h
7.35	READ SECTOR(S)	M	YES	RdSec, RDSK, REC	General	20h
7.36	READ SECTOR(S) EXT	M	YES	RdSecEx, RDSE, RSEX	48-bit Address	24h
7.37	READ STREAM DMA EXT	O	NO	RdStrDma, RSTD	Streaming	2Ah
7.38	READ STREAM EXT	O	NO	RdStrPio, RSTP	Streaming	2Bh
7.39	READ VERIFY SECTOR(S)	M	YES	RdVfy, RVFE	General	40h
7.40	READ VERIFY SECTOR(S) EXT	M	YES	RdVfyEx, RVFE	48-bit Address	42h
-	READ VERIFY SECTORS(S) (w/o retry)	Obs	YES			41h
-	RECALIBRATE	Obs	YES			10h
7.41	SECURITY DISABLE PASSWORD	M	YES	SecuDisPsw, SEDP	Security	F6h

ATA-8 REF	Commands	ATA-8	Sup	Key Word Option	Feature Set	OP
7.42	SECURITY ERASE PREPARE	M	YES	SecuErasePrep, SERP	Security	F3h
7.43	SECURITY ERASE UNIT	M	YES	SecuEraseUnit, SEEU	Security	F4h
7.44	SECURITY FREEZE LOCK	O	YES	SecuFrzLock, SFZL	Security	F5h
7.45	SECURITY SET PASSWORD	M	YES	SecuSetPsw, SESP	Security	F1h
7.46	SECURITY UNLOCK	M	YES	SecuUnlock, SEUL	Security	F2h
-	SEEK	M	YES			70h-7Fh
7.47	SERVICE	O	NO	Service, SRVC	TCQ	A2h
7.48	SET FEATURES	M	YES	SetFeature, SETF	General	EFh
7.49.2	SET MAX ADDRESS	M	YES	SetMaxAddr, SMXA, SMAX	HPA	F9h
7.49.3	SET MAX FREEZE LOCK	O	YES	SetMaxFrzLock, SMFL	HPA	F9h/04h
7.49.4	SET MAX LOCK	O	YES	SetMaxLock, SMLK	HPA	F9h/02h
7.49.5	SET MAX SET PASSWORD	O	YES	SetMaxSetPswd, SMSP	HPA	F9h/01h
7.49.6	SET MAX UNLOCK	O	YES	SetMaxUnlock, SMUN	HPA	F9h/03h
7.50	SET MAX ADDRESS EXT	M	YES	SetMaxEx, SAME	HPA	37h
7.51	SET MULTIPLE MODE	M	YES	SetMul, SMUL	General	C6h
7.52	SLEEP	M	YES	Sleep, SLEP	Power Manage	E6h
7.53.2	S.M.A.R.T. DISABLE OPERATION	M	YES	SmDisable, SDSO, SMDI	S.M.A.R.T.	B0h/D9h
-	S.M.A.R.T. ENABLE/DISABLE AUTO OFF-LINE	Obs	YES		S.M.A.R.T.	B0h-DBh
7.53.3	S.M.A.R.T. ENABLE/DISABLE AUTOSAVE	M	YES	SmAutoSv, SAAS, SMAS	S.M.A.R.T.	B0h/D2h
7.53.4	S.M.A.R.T. ENABLE OPERATION	M	YES	SmEnable, SESO, SMEN	S.M.A.R.T.	B0h/D8h
7.53.5	S.M.A.R.T. EXECUTE OFFLINE IMMEDIATE	O	YES	ExeSmOL, SEOI, SMOI	S.M.A.R.T.	B0h/D4h
7.53.6	S.M.A.R.T. READ DATA	O	YES	SmRdData, SRLS, SMRD	S.M.A.R.T.	B0h/D0h
7.53.7	S.M.A.R.T. READ LOG	O	YES	SmRdLog, SRLS, SMRL	S.M.A.R.T.	B0h/D5h
-	S.M.A.R.T. READ THRESHOLD	Obs	YES		S.M.A.R.T.	B0h-D1h
7.53.8	S.M.A.R.T. RETURN STATUS	O	YES	SmStatus, SRSS	S.M.A.R.T.	B0h/DAh
-	S.M.A.R.T. SAVE ATB VALUES	Obs	YES		S.M.A.R.T.	B0h-D3h
7.53.9	S.M.A.R.T. WRITE LOG	O	YES	SmWrLog, SWLS, SMWL	S.M.A.R.T.	B0h/D6h
7.54	STANDBY	M	YES	Standby, STBY	Power Manage	E2h
7.55	STANDBY IMMEDIATE	M	YES	StandbyIm, STBI	Power Manage	E0h
7.56	TRUSTED NON-DATA	O	NO		Trusted	5Bh
7.57	TRUSTED RECEIVE	O	NO		Trusted	5Ch
7.58	TRUSTED RECEIVE DMA	O	NO		Trusted	5Dh
7.59	TRUSTED SEND	O	NO		Trusted	5Eh
7.60	TRUSTED SEND DMA	O	NO		Trusted	5Fh

ATA-8 REF	Commands	ATA-8	Sup	Key Word Option	Feature Set	OP
7.61	WRITE BUFFER	O	YES	WrBuf, WBUF	General	E8h
7.62	WRITE DMA	M	YES	WdDma, WDMA	General	CAh
7.63	WRITE DMA EXT	M	YES	WrDmaEx, WDMX	48-bit Address	35h
7.64	WRITE DMA FUA EXT	M	YES	WrDmaFuaEx, WDFE	48-bit Address	3Dh
7.65	WRITE DMA QUEUED	O	NO	WrDmaQ, WDMQ	TCQ	CCh
7.66	WRITE DMA QUEUED EXT	O	NO	WrDmaQEx, WDQX	TCQ	36h
7.67	WRITE DMA QUEUE FUA EXT	O	NO	WrDmaQFuaEx, WDQF	TCQ	3Eh
-	WRITE DMA (w/o retry)	Obs	YES			CBh
7.68	WRITE FPDMA QUEUED	M	YES	WFPDMAQ, WDMA_NCQ	NCQ	61h
7.69	WRITE LOG EXT	M	YES	WrLogEx, WRLE	GPL	3Fh
7.70	WRITE LOG DMA EXT	O	YES			57h
7.71	WRITE MULTIPLE	M	YES	WrMul, WMUL	General	C5h
7.72	WRITE MULTIPLE EXT	M	YES	WrMulEx, WDME, WMEX	48-bit Address	39h
7.73	WRITE MULTIPLE FUA EXT	M	YES	WrMulFuaEx, WMFE	48-bit Address	CEh
7.74	WRITE SECTOR(S)	M	YES	WrSec, WDSK, WSEC	General	30h
7.75	WRITE SECTOR(S) EXT	M	YES	WrSecEx, WDSE, WSEX	48-bit Address	34h
-	WRITE SECTOR(S) (w/o retry)	Obs	YES			31h
7.76	WRITE STREAM DMA EXT	O	NO	WrStrDma, WSTD	Streaming	3Ah
7.77	WRITE STREAM EXT	O	NO	WrStrPio, WSTP	Streaming	3Bh
7.78	WRITE UNCORRECTABLE EXT	O	YES			45h
-	DATA SET MANAGEMENT EXT (I.E. TRIM)	O	YES			06h
Key: M – Mandatory, O – Optional, Obs – Obsolete, P – Prohibited, N – Not defined, YES – Supported, NO – Not Supported						

5.1.1 48-Bit Address Command Set

The Element SSD supports the 48-Bit Address command set consisting of:

- Flush Cache Ext
- Read DMA Ext
- Read native Max Address Ext
- Read Sector(s) Ext
- Set Max Address Ext
- Write DMA Ext
- Write Multiple Ext

- Write Sector(s) Ext

5.1.2 ATA General Feature Command Set

The Element SSD supports the ATA General Feature command set consisting of:

- Download Microcode
- Executive Device Diagnostics
- Flush Cache
- Identify Device
- NOP (optional)
- Read Buffer (optional)
- Read DMA
- Read Multiple
- Read Sector(s)
- Read Verify Sector(s)
- Seek
- Set Features
- Set Multiple Mode
- Write Buffer (optional)
- Write DMA
- Write Multiple
- Write Sector(s)

5.1.3 Device Configuration Overlay Command Set

The Element SSD supports the Device Configuration Overlay command set consisting of:

- Device Configuration Freeze Lock
- Device Configuration Identity
- Device Configuration Restore
- Device Configuration Set

5.1.4 General Purpose Log Command Set

The Element SSD supports the General Purpose Log command set consisting of:

- Read Log Ext
- Write Log Ext

5.1.5 Host Protected Area Command Set

The Element SSD supports the Host Protected Area command set consisting of:

- Read Native Max Address
- Read Native Max Address Ext

- Set Max Address
- Set Max Address Ext
- Set Max Freeze Lock (optional)
- Set Max Lock (optional)
- Set Max Set Password (optional)
- Set Max Unlock (optional)

5.1.6 Power Management Command Set

The Element SSD supports the Power Management command set consisting of:

- Check Power Mode
- Idle
- Idle Immediate
- Sleep
- Standby
- Standby Immediate

5.1.7 Security Mode Feature Set

The Element SSD supports the Security Mode command set consisting of:

- Security Set Password (OPCODE: F1h)
- Security Unlock (OPCODE: F2h)
- Security Erase Prepare (OPCODE: F3h)
- Security Erase Unit (OPCODE: F4h)
- Security Freeze Lock (OPCODE: F5h)
- Security Disable Password (OPCODE: F6h)

5.1.8 S.M.A.R.T. Support

Data storage drives capture a variety of information during operation that may be used to analyze drive —health. Drive manufacturers have adopted S.M.A.R.T. (Self-Monitoring, Analysis, and Reporting Technology) to help warn system software, a system administrator, or a user of impending drive failure, while time remains to take preventive action. The technical documentation for S.M.A.R.T. is captured in the AT Attachment (ATA) standard. The standard defines the protocols for reporting errors and for invoking self-tests to collect and analyze data on demand. The ATA specification is flexible and provides for individual manufacturers to define their own unique vendor specific information. This section describes the baseline supported S.M.A.R.T. command attributes. The information herein should be used in conjunction with the ATA standard and related documents, which may serve as references for topics and details not

Manual	1/2/2014
PSFS1XXXXGXXXX	Viking Technology
Revision B7	Page 36 of 60

addressed here. Further, it is recommended to consult the list of public S.M.A.R.T. attributes.

5.1.8.1 S.M.A.R.T. Command Set

The supported S.M.A.R.T. command set is listed in the table below. See the AT Attachment standard for implementation details.

Table 5-3: S.M.A.R.T. Command Set

Value (hex)	Command
00-CF	Reserved
D0	S.M.A.R.T. read attributes
D1*	S.M.A.R.T. read threshold
D2	S.M.A.R.T. enable/disable attribute autosave
D3*	S.M.A.R.T. save attribute values
D4	S.M.A.R.T. execute off-line immediate
D5	S.M.A.R.T. read log sector
D6	S.M.A.R.T. write log sector
D7*	S.M.A.R.T. write attribute threshold
D8	S.M.A.R.T. enable operations
D9	S.M.A.R.T. disable operations
DA	S.M.A.R.T. return status
DB	S.M.A.R.T. enable/disable automatic off-line
DC-FF	Reserved (Vendor Specific)
* Note that D1, D3, and D7 have been made obsolete in the ATA-8 specification.	

5.1.8.2 Off-line Mode

The Element SSD supports the optional 28-bit S.M.A.R.T. EXECUTION OFF-LINE IMMEDIATE (B0h/D4h) command per the ATA-8 specification. This command causes the Element SSD to initiate the collection of S.M.A.R.T. data in an off-line mode and then preserves this data across power and reset events. Supported subcommands include those shown in the table below. Reference the ATA-8 specification for subcommand detail.

Table 5-4: Supported S.M.A.R.T. EXECUTE OFF-LINE IMMEDIATE Subcommands

Value	Description
00h	Execute S.M.A.R.T. off-line routine immediately in off-line mode
01h	Execute S.M.A.R.T. Short self-test routine immediately in off-line mode
02h	Execute S.M.A.R.T. Extended self-test routine immediately in off-line mode
04h	Execute S.M.A.R.T. Selective self-test routine immediately in off-line mode
7Fh	Abort off-line mode self-test routine
81h	Execute S.M.A.R.T. Short self-test routine immediately in captive mode
82h	Execute S.M.A.R.T. Extended self-test routine immediately in captive mode
84h	Execute S.M.A.R.T. Selective self-test routine immediately in captive mode

5.1.8.3 Captive Mode

When executing a self-test in captive mode, the Element SSD executes the self-test routine after receipt of the command. At the end of the routine the Element SSD places the results of this routine in the self-test execution status byte and reports command completion. If an error occurs while the Element SSD is performing the routine it discontinues its testing, place the results of this routine in the self-test execution status byte and the DST log page, and complete the command.

5.1.8.4 S.M.A.R.T. Logs

S.M.A.R.T. logs are intended to enhance S.M.A.R.T. Attribute information by capturing additional drive details at appropriate times. This information may lead to improved error detection and reporting capability. The controller supports S.M.A.R.T. logs, and relevant tests, events, and conditions each have an associated log. S.M.A.R.T. logs conform to industry-standard structures.

The reported size of each log is reported by the Log Directory (Log 0). Note that the information returned via S.M.A.R.T. Read Log access to Log 0 is more limited than that via GP Read Log. Log size is only reported the LSB (max 255 blocks) when access via S.M.A.R.T. Read Log command; and full 2 bytes (max 65535 blocks) when access via Read Log EXT command.

The frequency at which S.M.A.R.T. logs are updated is the frequency at which checkpoint information is saved. That frequency is related to data volume, and can range between approximately 2 seconds and 2 minutes, depending on how

much data is being transferred. Therefore, constant host system IOs cause check-pointing and S.M.A.R.T. log update relatively frequently (approximately every 2 seconds); very slow or idle host transaction rates result in check-pointing and S.M.A.R.T. log update less frequently (worst-case around every 2 minutes).

All logs are non-volatile except as within each of the log description.

Handling and reporting error conditions relating to the updating of S.M.A.R.T. logs and S.M.A.R.T. Attributes is accomplished the same as handling error conditions experienced while saving user data. Likewise, handling and reporting error conditions relating to other processes (including background processes) that occur while updating S.M.A.R.T. logs and S.M.A.R.T. Attributes is accomplished the same as handling such error conditions while saving user data. S.M.A.R.T. logs are validated by affecting the events being detected and logged; the S.M.A.R.T. log always reflects the event that occurred, whether that event is injected artificially or occurs independently.

5.1.9 S.M.A.R.T. Attributes

5.1.9.1 Supported (Baseline) Attributes

The following table shows the supported S.M.A.R.T. attributes.

Table 5-5: Baseline S.M.A.R.T. Attribute Summary

ID	Hex	Attribute Name	Description
1	0x01	Raw Read Error Rate	Raw error rate related to ECC errors. Correctable and uncorrectable RAISE errors are included in the error event count. (UECC + URAISE)
5	0x05	Retired Block Count	Tracks the total number of retired blocks.
9	0x09	Power-On Hours (POH)	Count of hours in power-on state. The raw value of this attribute shows total count of hours in power-on state.
12	0x0C	Device Power Cycle Count	This attribute indicates the count of full hard disk power on/off cycles.
13	0x0D	Soft Read Error Rate	The number of corrected (CECC) read errors reported. This feature is not available for industrial versions, which are VRFS1xGA, VRFS1xGK and VRFS1xGM.
100	0x64	Gigabytes Erased	This attribute counts the Gigabytes of Flash memory erases across the entire drive, over the life of the drive. This feature is not available for industrial versions, which are VRFS1xGA, VRFS1xGK and VRFS1xGM.
170	0xAA	Reserved Block Count	The number of reserved spares for bad block handling. This feature is not available for

ID	Hex	Attribute Name	Description
			industrial versions, which are VRFS1xGA, VRFS1xGK and VRFS1xGM.
171/181	0xAB	Program Fail Count	Counts the number of flash program failures
172/182	0xAC	Erase Fail Count	Counts the number of flash erase failures
174	0xAE	Unexpected power loss	Controller has detected a loss of power
177	0xB1	Wear range Delta	% from most to least worn
184	0xB8	Reported I/O Error Detection Code Rate	I/O Error Detection Code rate. This attribute tracks the number of end-to-end CRC errors encountered during host initiated reads and writes. This feature is not available for industrial versions, which are VRFS1xGA, VRFS1xGK and VRFS1xGM.
187	0xBB	Reported Uncorrectable Errors	This attribute tracks the number of uncorrectable RAISE (URAISE) errors reported back to the host for all data access commands.
194	0xC2	Temperature	Temperature assuming an on-board sensor connected via Industry Standard Two Wire Interface (ISTW) interface to the controller.
195	0xC3	ECC On the Fly Count	This attribute tracks the number of uncorrectable errors (UECC).
196	0xC4	Reallocation Count	This attribute tracks the number of blocks that fail programming which are reallocated as a result.
198	0xC6	Uncorrectable Sector Count	The total number of uncorrectable RAISE (URAISE) errors when reading/writing a sector. A rise in the value of this attribute indicates defects of the flash memory device. This feature is not available for industrial versions, which are VRFS1xGA, VRFS1xGK and VRFS1xGM.
199	0xC7	SATA R-Errors (CRC) Error Count	SATA R-Errors (CRC) Error Count. This feature is not available for industrial versions, which are VRFS1xGA, VRFS1xGK and VRFS1xGM.
201	0xC9	Uncorrectable Soft Read Error Rate	Number of soft read errors that cannot be fixed on-the-fly and requires deep recovery via RAISE. (ie UECC)
204	0xCC	Soft ECC Correction Rate	Number of errors corrected by RAISE that cannot be fixed on-the-fly and requires ECC (multilevel) to correct. (ie UECC)
230	0xE6	Life Curve Status	A life curve used to help predict life in terms of the endurance based on the number of writes to flash. This feature is not available for industrial versions, which are VRFS1xGA, VRFS1xGK and VRFS1xGM.
231	0xE7	SSD Life Left	Indicates the approximate percentage of SSD life left.
232	0xE8	Available Reserved Space	The number of reserved blocks remaining. This feature is not available for industrial versions, which are VRFS1xGA, VRFS1xGK and

ID	Hex	Attribute Name	Description
			VRFS1xGM.
235	0xEB	Power Fail Backup Health	Health of the Holdup Circuit. This feature is not available for industrial versions, which are VRFS1xGA, VRFS1xGK and VRFS1xGM.
241	0xF1	Lifetime Writes from Host	Indicates the total amount of data written from hosts since the drive was deployed.
242	0xF2	Lifetime Reads to Host	Indicates the total amount of data read to hosts since the drive was deployed.

Notes:

1. SMART ID# 233 and 234 are for Internal Use only.

A number of S.M.A.R.T. attributes relate to correctable and uncorrectable ECC, and RAISE errors. The figure below summarizes each ECC and RAISE error category and shows which errors the applicable S.M.A.R.T. attributes track.

Figure 5-1: S.M.A.R.T. ECC and RAISE Error Summary

ERROR TYPE		ATTRIBUTE NO.	
Severity ↑	RAISE uncorrectable (URAISE)	198	187
	ECC uncorrectable – RAISE correctable (UECC)	195	201 204
	ECC correctable (CECC)	13	

Figure 5-2: S.M.A.R.T. ECC and RAISE Error Summary for Industrial versions of VRFS1xGA and VRFS1xGK

ERROR TYPE		ATTRIBUTE NO.	
Severity ↑	RAISE uncorrectable (URAISE)	187	
	ECC uncorrectable – RAISE correctable (UECC)	195	201 204

5.1.9.2 Supported Baseline Attribute Details

The table below provides a detailed description of supported S.M.A.R.T. attributes and how they may be used.

Table 5-6: Baseline S.M.A.R.T. Attribute Details

ID	Attribute Name	Description	Rational
1	Raw Read Error Rate	Raw error rate related to ECC errors. Errors are counted as ECC errors above a threshold. For the CONTROLLER, this attribute includes Uncorrectable ECC (UECC) errors, and Uncorrectable RAISE (URAISE) errors. <u>Normalized Equation:</u> $10\log_{10}(\text{BitsRead}/\text{ReadErrors} + 1)$ SectorsRead= Number of sectors read SectorsToBits= 512*8 BitsRead= SectorsRead*SectorsToBits <u>Normalized Value Range:</u> Best = 100 Worst = 1 Invalid = 0 <u>Raw Usage:</u> [3-0] : Number of sectors read [6-4]: Read errors (UECC+URAISE)	The Raw Read error rate includes two types of ECC errors that are tracked by the CONTROLLER: UECC and URAISE. The normalized equation for Raw read error rate is logarithmic since the valid BER range of the attribute spans from 1.00E-10 to 1.00E-12. To force positive numbers, the numerator and denominator are flipped. One is then added to the number of errors in the denominator to avoid a divide-by-0 condition if no errors are encountered. By taking the log of the inverted BER and multiplying by ten a reasonable range of normalized values from 120 to 38 (representing a BER range of 1.00E-13 to 1.68E-04) are presented. This Attribute reads '0' until a sample size between 10E10 and 10E12 is available to be tracked by this Attribute.

ID	Attribute Name	Description	Rational
5	Retired Block Count	Tracks the total number of retired blocks. <u>Normalized Equation:</u> $\text{Count} = 100 - (100 * \text{RBC} / \text{MRB})$ RBC = RetiredBlockCount = Number of retired blocks. MRB = MinimumReqBlocks = Minimum number of reserve blocks available for CONTROLLER use. This value is set at factory configuration time. <u>Normalized Value Range:</u> Best = 100 Worst = 1 <u>Raw Usage:</u> [3-0] : Retired block count [6-4] : None (0x00)	The normalized equation for this attribute decrements as blocks are retired and the reserve (over-provisioned) block count is decremented. (Note that all blocks, including reserve blocks, are in service at all times; reserve blocks constitute Flash memory space over and above the drive's logical capacity.) As defined, this attribute is identical to the Reallocation Event Count attribute (#196).
9	Power-On Hours (POH)	Count of hours in power-on state. The raw value of this attribute shows total count of hours in the power-on state. <u>Normalized Equation:</u> $100 - (\text{POH} / \text{HPY} * 10)$ <u>Normalized Value Range:</u> Best = 100 Worst = 1 <u>Raw Usage:</u> [3-0] : Total number of power-on hours [6-4]: total number of milliseconds since last hour update	The normalized equation for Power-On hours decrements by 1 each 1/10 year. Note that some manufacturers elect to decrement by 1 for each 1/12 year of POH.

ID	Attribute Name	Description	Rational
12	Device Power Cycle Count	This attribute indicates the count of full hard disk power on/off cycles. <u>Normalized Equation:</u> $100 - (PCC / 1024)$ <u>Normalized Value Range:</u> Best = 100 Worst = 1 <u>Raw Usage:</u> [3-0] : Cumulative lifetime power cycle count (PCC) [6-4] : None (0x00)	The normalized equation for Power Cycle Count decrements by 1 for each 1024 power cycle.
13	Soft Read Error Rate	This attribute tracks the number of correctable ECC errors (CECC). The normalized value is only computed when the number of bits in the "BitsRead" count is in the range of 10^{10} to 10^{12}. The count is cleared at power-on reset and wraps to 0.5×10^{10} when it exceeds 10^{12}. <u>Normalized Equation:</u> $10 \log_{10}(\text{BitsRead} / \text{SoftReadErrors} + 1)$ SectorsRead= Number of sectors read SectorsToBits= 512×8 BitsRead= SectorsRead*SectorsToBits <u>Normalized Value Range:</u> Best = 100 Worst = 1 Invalid = 0 <u>Raw Usage:</u> [3-0] : Number of sectors read [6-4]: Soft Read Error Count (CECC)	The Soft Read Error Rate includes all correctable ECC (CECC) errors tracked by the CONTROLLER. The normalized equation for Soft Read Error Rate is logarithmic since the valid BER range of the attribute spans from $1.00\text{E}-10$ to $1.00\text{E}-12$. To force positive numbers, the numerator and denominator are flipped. One is then added to the number of errors in the denominator to avoid a divide-by-0 condition if no errors are encountered. By taking the log of the inverted BER and multiplying by ten a reasonable range of normalized values from 120 to 38 (representing a BER range of $1.00\text{E}-13$ to $1.68\text{E}-04$) are presented. This Attribute reads '0' until a sample size between $10\text{E}10$ and $10\text{E}12$ is available to be tracked by this Attribute.
100	Gigabytes Erased	This attribute counts the Gigabytes of Flash memory erases across the entire drive, over the life of the drive. <u>Raw Usage:</u> [3-0]: Gigabytes Erased [6-4]: None (0x00)	This Attribute returns a byte count in increments of 64 GBytes. The count represents the number of bytes erased. The Attribute reads '0' until the byte count reaches 64 GB, at which time the Attribute changes to read '64' (decimal). For Flash memory consisting of 128-page blocks, each page of which is 4k bytes, each 64 GB increment represents an

ID	Attribute Name	Description	Rational
			additional 128,000 blocks erased.
170	Reserve Block Count	The number of reserve Flash memory blocks. Usage: [3-0] : Reserve block count [6-4] : None (0x00)	This Attribute is related to attribute 5: Retired Block Count. It provides a count of reserve (over-provisioned) blocks. (Note that all blocks, including reserve blocks, are in service at all times; reserve blocks constitute Flash memory space over and above the drive's logical capacity.) The Attribute value is initially the total Reserve Block count. The value is decremented as the reserve block count diminishes over the drive's life.
171	Program Fail Count	Counts the number of flash program failures. Usage: [3-0] : Program Error Count [6-4] : None (0x00)	This Attribute returns the total number of Flash program operation failures since the drive was deployed. This Attribute is identical to Attribute 181.
172	Erase Fail Count	Counts the number of flash erase failures. Usage: [3-0] : Erase Error Count [6-4] : None (0x00)	This Attribute returns the total number of Flash erase operation failures since the drive was deployed. This Attribute is identical to Attribute 182.
174	Unexpected Power Loss	Counts the number of unexpected power loss events, as determined by the number of times PFAIL has been asserted (or other criteria?).	This Attribute returns the total number of unexpected power loss events over the life of the drive.

ID	Attribute Name	Description	Rational
		<u>Usage:</u> [3-0] : Unexpected Power Loss Event Count [6-4] : None (0x00)	
177	Wear Range Delta	Provides a value equal to the delta between the max worn Flash block and the least worn Flash block, as a percentage of the max rated wear of the SSD. <u>Equation:</u> $\text{Wear Range Delta} = \frac{(\text{MW} - \text{LW})}{\text{MRW}} \times 100$ MW = P-E Cycles experienced by Most Worn block LW = P-E Cycles experienced by Least Worn block MRW = Max Rated Wear = P-E Cycle rating for the Flash memory <u>Usage:</u> [3-0] : Wear Range delta [6-4] : None (0x00)	This Attribute identifies the “delta” between most-worn and least-worn Flash blocks, as a percentage of the max rated wear of the Flash memory on the SSD. For 10,000-cycle Flash, where 1% of rated cycles is 100 cycles, a value of 1.5 for this Attribute means the difference in wear between the least worn block and the most-worn block is 150 Erase cycles. This attribute may not be accurate until approximately 10% of drive life has been used.
181	Program Fail Count	Counts the number of flash program failures. <u>Usage:</u> [3-0] : Program Error Count [6-4] : None (0x00)	This Attribute returns the total number of Flash program operation failures since the drive was deployed. This Attribute is identical to Attribute 171.
182	Erase Fail Count	Counts the number of flash erase failures. <u>Usage:</u> [3-0] : Erase Error Count [6-4] : None (0x00)	This Attribute returns the total number of Flash erase operation failures since the drive was deployed. This Attribute is identical to Attribute 172.

ID	Attribute Name	Description	Rational
184	Reported I/O Error Detection Code Errors (IOEDC errors)	Error Detection Code Errors (IOEDC errors) This attribute tracks the number of I/O errors encountered during reads from flash memory. Normalized Equation: $100 - (\text{IOEDC Errors})$ Normalized Value Range: Best = 100 Worst = 1 Raw Usage: [3-0] : Cumulative lifetime IOEDC error count [6-4] : None (0x00)	The CONTROLLER SSD processor minimizes the risk of unreported data miscompares by calculating and appending a CRC based on the data and L-page location as it writes to flash. The CRC is subsequently verified when data is read. This attribute tracks any CRC errors encountered in this path. The normalized equation for IOEDC Error Count decrements by 1 for each IOEDC error.
187	Reported Uncorrectable Errors (URAISE)	Uncorrectable Errors (URAISE) This attribute tracks the number of uncorrectable RAISE (URAISE) errors reported back to the host for all data access commands. Normalized Equation: $100 - (\text{URAISE})$ Normalized Value Range: Best = 100 Worst = 1 Raw Usage: [1-0] : Cumulative lifetime URAISE errors [6-2] : None (0x00)	The uncorrectable ECC error rate tracks the CONTROLLER Uncorrectable RAISE (URAISE) errors. The normalized equation for Uncorrectable Error Count decrements by 1 for each URAISE error. Uncorrectable errors reported in this field are uncorrectable by any level of ECC protection including RAISE.
194	Temperature	Temperature of the SSD assembly. That is, the temperature inside the SSD housing. Normalized Equation: $\text{Temperature} = \text{Temperature (Celsius)}$ Normalized Value Range: Lowest = -127 Highest = 127 Raw Usage: [1-0] : Current temperature (C; from sensor) [3-2]: Highest temperature (C; since	The normalized temperature is a straight Celsius value as obtained from the primary SSD temperature sensor. The raw values represent current and historical Celsius temperature values from the primary SSD temperature sensor. For SSD designs incorporating multiple temperature sensors, current temperature is taken from the sensor with the highest

ID	Attribute Name	Description	Rational
		power-on) [5-4]: Lowest temperature (C; since power-on) [6] : None (0x00)	reading; historical values are highest or lowest of all sensors polled.
195	ECC On-the-Fly Error Count	This attribute tracks the number of uncorrectable ECC errors (UECC). The normalized value is only computed when the number of bits in the "BitsRead" count is in the range of 10^{10} to 10^{12}. The count is cleared at power on reset and when $>10^{12}$ bits have been read. <u>Normalized Equation:</u> $10 \log_{10}(\text{BitsRead} / \text{ECCOnTheFlyErrors} + 1)$ SectorsRead= Number of sectors read SectorsToBits= $512 * 8$ BitsRead= SectorsRead*SectorsToBits <u>Normalized Value Range:</u> Best = 100 Worst = 1 Invalid = 0 <u>Raw Usage:</u> [3-0] : Number of sectors read [6-4]: ECCOnTheFlyErrors (UECC) count	The ECC On The Fly error rate includes all uncorrectable ECC errors (UECC) tracked by the CONTROLLER. The normalized equation for ECC On The Fly error rate is logarithmic since the valid BER range of the attribute spans from $1.00\text{E-}10$ to $1.00\text{E-}12$. To force positive numbers, the numerator and denominator are flipped. One is then added to the number of errors in the denominator to avoid a divide-by-0 condition if no errors are encountered. By taking the log of the inverted BER and multiplying by ten a reasonable range of normalized values from 120 to 38 (representing a BER range of $1.00\text{E-}13$ to $1.68\text{E-}04$) are presented. As defined, this Attribute is identical to Attribute 201 and Attribute 204. This Attribute reads '0' until a sample size between $10\text{E}10$ and $10\text{E}12$ is available to be tracked by this Attribute. Note that many UECC errors counted by this Attribute are corrected by RAISE correction.

ID	Attribute Name	Description	Rational
196	Reallocation Event Count	Tracks the total number of reallocated Flash blocks. <u>Normalized Equation:</u> $\text{Count} = 100 - (100 * \text{RBC} / \text{MRB})$ RBC = RetiredBlockCount = Number of retired blocks. MRB = MinimumReqBlocks = Minimum number of reserve blocks available for CONTROLLER use. This value is set at factory configuration time. <u>Normalized Value Range:</u> Best = 100 Worst = 1 <u>Raw Usage:</u> [3-0] : Retired block count [6-4] : None (0x00)	The normalized equation for this attribute decrements as blocks are retired and the reserve (over-provisioned) block count is decremented. (Note that all blocks, including reserve blocks, are in service at all times; reserve blocks constitute Flash memory space over and above the drive's logical capacity.) As defined, this attribute is identical to the Retired Block Count attribute (#5).
198	Uncorrectable Sector Count	The total number of uncorrectable errors when reading/writing a sector. A rise in the value of this attribute indicates defects of the flash memory device. Note that the native CONTROLLER sector size is 4k bytes. <u>Normalized Equation:</u> $10 * \log_{10}(\text{TotalSectors} / \text{URAISE} + 1)$ TotalSectors= Total number of sectors on the drive. URAISE= Uncorrectable Error Count <u>Normalized Value Range:</u> Best = 120 Worst = 1 Invalid = 0 <u>Raw Usage:</u> [3-0] : Uncorrectable sector count (URAISE) this power cycle [6-4] : Number of sectors read this power cycle	The difference between this count and reported uncorrectable will be those errors correctable by RAISE. The normalized equation for this Attribute is logarithmic since the valid BER range of the attribute spans from 1.00E-10 to 1.00E-12. This Attribute reads '120' until a sample size between 10E10 and 10E12 is available to be tracked by this Attribute.

ID	Attribute Name	Description	Rational
199	SATA R-Errors Error Count	This attribute tracks the number SATA TX R_Errors + SATA RX R_Errors. Normalized Equation: $200 - (R_Errors * SampleSize / NumSectorsTransferred)$ SampleSize= 8000 NumSectorsTransferred= Total number of sectors transferred to/from Host Normalized Value Range: Best = 100 Worst = 1 Raw Usage: [3-0] : Current SATA RError count [6-4] : None (0x00)	Normalized equation implemented per Customer request.
201	Uncorrectable Soft Read Error (UECC)	Number of soft read errors that cannot be fixed on-the-fly and requires deep recovery provided by RAISE. The normalized value is only computed when the number of bits in the "BitsRead" count is in the range of 10^{10} to 10^{12}. The count is cleared at power on reset and when $>10^{12}$ bits have been read. Normalized Equation: $10\log_{10}(\text{BitsRead}/\text{UECC} + 1)$ SectorsRead= Number of sectors read SectorsToBits= $512 * 8$ BitsRead= SectorsRead*SectorsToBits Normalized Value Range: Best = 100 Worst = 1 Invalid = 0 Raw Usage: [3-0] : Number of sectors read [6-4]: Uncorrectable Soft error count (UECC)	The Uncorrectable Soft Read Error Rate includes all uncorrectable ECC (UECC) errors tracked by the CONTROLLER. The normalized equation for Uncorrectable Soft Read Error Rate is logarithmic since the valid BER range of the attribute spans from $1.00E-10$ to $1.00E-12$. To force positive numbers, the numerator and denominator are flipped. One is then added to the number of errors in the denominator to avoid a divide-by-0 condition if no errors are encountered. By taking the log of the inverted BER and multiplying by ten a reasonable range of normalized values from 120 to 38 (representing a BER range of $1.00E-13$ to $1.68E-04$) are presented. As defined this attribute is identical to 195 and 204. This Attribute reads '0' until a sample size between $10E10$ and $10E12$ is available to be tracked by this Attribute.

ID	Attribute Name	Description	Rational
204	Soft ECC Correction Rate (UECC)	Number of errors corrected by RAISE that cannot be fixed on-the-fly and requires RAISE to correct. The normalized value is only computed when the number of bits in the "BitsRead" count is in the range of 10^{10} to 10^{12}. The count is cleared at power on reset and when $>10^{12}$ bits have been read. Normalized Equation: $10\log_{10}(\text{BitsRead}/\text{UECC} + 1)$ SectorsRead= Number of sectors read SectorsToBits= 512×8 BitsRead= SectorsRead*SectorsToBits Normalized Value Range: Best = 100 Worst = 1 Invalid = 0 Raw Usage: [3-0] : Number of sectors read [6-4]: Soft ECC correction count (UECC)	The Soft ECC Correction Rate includes all uncorrectable ECC (UECC) errors tracked by the CONTROLLER. The normalized equation for Soft ECC Correction Rate is logarithmic since the valid BER range of the attribute spans from $1.00\text{E}-10$ to $1.00\text{E}-12$. To force positive numbers, the numerator and denominator are flipped. One is then added to the number of errors in the denominator to avoid a divide-by-0 condition if no errors are encountered. By taking the log of the inverted BER and multiplying by ten a reasonable range of normalized values from 120 to 38 (representing a BER range of $1.00\text{E}-13$ to $1.68\text{E}-04$) are presented. As defined this attribute is identical to 195 and 201. This Attribute reads '0' until a sample size between $10\text{E}10$ and $10\text{E}12$ is available to be tracked by this Attribute.
230	Life Curve Status	Current state of drive operation based upon the Life Curve, which is the Flash Program-Erase Cycle usage schedule defined for the drive's warranty period configured by Viking at manufacturing time. Normalized Equation: $100 = \text{usage does not require throttling}$, $90 = \text{throttling}$ Normalized Value Range: Best = 100 (positive wrt Life Curve) Worst = 1 (throttling) RawUsage: none	When no throttling is in effect, this value reads 100. If the PE Cycle usage trajectory threatens to violate the Life Curve usage schedule for the block that has the minimum PE cycles left unused, throttling commences to forbid such violation; this value reads 90 while throttling is in effect. If throttling is disabled, this value reads 100 (i.e., throttling is not in effect).

ID	Attribute Name	Description	Rational
231	SSD Life Left	Indicates the approximate SSD life left, in terms of PE cycles and Flash blocks currently available for use. Normalized Equation: $SSD\ Life\ Left = MIN[MAX(termA, 10), termB]$ $termA = (Unused)/(Rated) \times 100$ $Unused = (unused\ PE\ cycles)$ $Rated = (rated\ PE\ cycles)$ $termB = (AvailExcess)/(OrigExcess)$ $AvailX = (Blocks\ above\ min\ req'd)$ $OrigX = (Original\ blks\ above\ min\ req'd)$ Normalized Value Range: 100 = Best = Full SSD life remains 10 = Replace = Sufficient Flash blocks still in service, but rated PE Cycles consumed 1 = Worst = Insufficient Flash blocks remain in service; EOL; drive is read-only	SSD life left is based on actual usage and takes into account PE cycle consumption and Flash block retirement. PE cycle usage at a rate less than the rate used for performance throttling will result in extending drive life. Actual Flash endurance remaining is normally greater than the unused rated PE cycles. Note that block retirement rate also affects SSD life and this Attribute value.
232	Available Reserved Space	Indicates the amount of Flash memory space in reserve. This is the Reserve Block Count (Attribute 170) represented in Gigabytes. Usage: [3-0]: $[(RB) \times (PPB) \times (BPP)] / (1024^3)$ [6-4] : None (0x00) RB = Reserve Blocks (see Attribute 170) PPB = Pages per Block BPP = Bytes per Page	This Attribute returns a count of GB equal to the number of Flash Blocks in service over and above the minimum block count required. This Attribute is Attribute 170 presented in units of GB. The Attribute value is returned in units of Gigabytes at an update resolution of 64 GBytes. The value is initially the number of GB equal to the total Reserve Block Count. As the value is updated (decremented), it decrements in 64GB resolution. For example, if the initial value is n, the next update will decrement the value to (n – 64GB).
235	Power Fail Backup Health	Indicates the condition of an external holdup circuit based on test results from the flash controller "Holdup Circuit Test". Normalized Equation: $min(100, (100 * (scapCurDischgMs - 10) /$	Power Fail Backup is an estimation of capacitive hold-up capability based on a timed discharge test, wherein discharge (past a predefined voltage threshold) faster than a predefined time-value threshold indicates a capacitor bank

ID	Attribute Name	Description	Rational
		$(\min(\text{scapTestDischgToutMs}, \text{scapInitDischgMs}) - 10))$ where scapCurDischgMs = Most recent discharge time (limited by apTestDischgToutMs). scapTestDischgToutMs = timeout "ceiling" (msec), specified via ConfigDrive Unique scapInitDischgMs = Initial discharge time for Holdup Circuit characterization at mfg time (characterization may be performed with a higher timeout "ceiling") <u>Normalized Value Range:</u> Best = 100 ("Holdup Circuit Test" passed) Worst = 1 (indicates the hold-up capability has degraded too far) <u>Raw Usage:</u> [1-0]: Latest "Holdup Circuit Test" discharge time (in milliseconds). [6-2]: None (0x00)	whose capacitance value is degraded past the point of reliability to protect SSD data. If an SSD has never run a "Holdup Circuit Test", the normalized value of this Attribute remains at '100'. This feature is not available for industrial versions, which are VRFS1xGA, VRFS1xGK and VRFS1xGM
241	Lifetime Writes from Host System	Indicates the number of bytes (in 64GB resolution) written to the drive by a host system, over the life of the drive. <u>Usage:</u> [3-0]: Count of 64GB units written [6-4] : None (0x00)	This Attribute returns a byte count, in units of Gigabytes at an update resolution of 64 GBytes. The count represents the number of bytes written. The Attribute reads '0' until the number of bytes written reaches 64GB; at 64GB the Attribute increments to a value of '64' (decimal).
242	Lifetime Reads to Host System	Indicates the number of bytes (in 64GB resolution) read from the drive by a host system, over the life of the drive. <u>Usage:</u> [3-0]: Count of 64GB units read [6-4] : None (0x00)	This Attribute returns a byte count, in units of Gigabytes at an update resolution of 64 GB. The count represents the number of bytes read. The Attribute reads '0' until the number of bytes read reaches 64GB; at 64GB the count increments to a value of '64' (decimal).

Table 5-7: S.M.A.R.T Attribute Default Threshold Values & Clear Conditions

This table shows the default threshold values and conditions that clear the S.M.A.R.T attributes.

ID	Attribute Name	Power Cycle	Format (Function Code 1)	Secure Erase	FW Update	ClearSMART Diag Cmd	Mfg load (MF + FW)	Default SMART Trip Threshold
1	Raw Read Error Rate	Clear	Clear	Clear	Clear	Clear	Clear	32h
5	Retired Block Count					Note 2	Clear	3
9	Power-On Hours (POH)					Clear	Clear	0
12	Device Power Cycle Count					Clear	Clear	0
13*	Soft Read Error Rate	Clear	Clear	Clear	Clear	Clear	Clear	0
100*	Gigabytes Erased					Clear	Clear	0
170*	Reserved Block Count						Clear	0
171/181	Program Fail Count					Clear	Clear	0
172/182	Erase Fail Count					Clear	Clear	0
174	Unexpected power loss					Clear	Clear	0
177	Wear range Delta					Clear	Clear	0
184*	Reported I/O Error Detection Code Rate					Clear	Clear	5Ah
187	Reported Uncorrectable Errors					Clear	Clear	0
194	Temperature					Clear	Clear	0
195	ECC On the Fly Count	Clear	Clear	Clear	Clear	Clear	Clear	0
196	Reallocation Count					Clear	Clear	3
198*	Uncorrectable Sector Count	Clear	Clear	Clear	Clear	Clear	Clear	0
199*	SATA R-Errors (CRC) Error Count	Clear	Clear	Clear	Clear	Clear	Clear	0
201	Uncorrectable Soft Read Error Rate	Clear	Clear	Clear	Clear	Clear	Clear	0
204	Soft ECC Correction Rate	Clear	Clear	Clear	Clear	Clear	Clear	0
230	Life Curve Status						Clear	0
231	SSD Life Left						Clear	0Ah
232*	Available Reserved Space					Clear	Clear	0
235**	Power Fail Backup Health					Clear	Clear	2
241	Lifetime Writes from Host					Clear	Clear	0
242	Lifetime Reads to Host					Clear	Clear	0

Notes:

1. All attributes are persistent (not cleared) unless otherwise specified.
2. Raw data is cleared by the ClearSMART Diagnostic Command
3. * indicates that this attribute is for the enterprise series only (VRFS1xGA and VRFS1xGF).
4. ** indicates that this feature is not available on VRFS1xGA and VRFS1xGF.

5.1.10 Attribute Sector

The S.M.A.R.T. Attribute Sector defines attribute format and the data structure is defined in the following table.

Table 5-8: S.M.A.R.T. Attribute Data Structure

Byte	Description
0:1	S.M.A.R.T. structure version number
2	First Stored Attribute Number (i.e. "1" for RawErrorRate)
3:4	Status
5	Nominal value
6	Worst value since SSD was deployed
7:12	Raw Data
13	Reserved
14:25	Next Stored Attribute Number (ie "3" for "Retired Block Count")
26:361	Next Stored Attribute Numbers (max 30 collected Attributes, including above)
362	Off-line data collection status
363	Self-test execution status byte
364:365	Total time to complete off-line data collection (in seconds)
366	Reserved
367	Off-line Data Collection capability
368:369	S.M.A.R.T. capability
370	Error Logging Capability (bit 0 set = device error logging supported)
371	Next Self Test Step
372	Short Self Test routine recommended polling time (in minutes)
373	Extended Self Test routine recommended polling time (in minutes)
374	Recommended polling time for Conveyance Self Test
375:376	Time for Extended Self Test if > 255 (ie, 373 to FFh)
377:385	Reserved
386:510	Vendor Information
511	Checksum of data structure (generated on retrieval of stored data)

Notes: Bytes 2:361 are vendor unique

5.1.11 Threshold Sector

The S.M.A.R.T. Threshold Sector defines attribute trip thresholds. Attributes are compared to the thresholds when the S.M.A.R.T. Return Status Command (DA) retrieves drive reliability Status. The S.M.A.R.T. Read Threshold Sector Command (DI) then used to read this information. Threshold information may be

modified or written via the S.M.A.R.T. Write Threshold Value Command (D7). Threshold values are obtained from the Saved Configuration Page.

Table 5-9: S.M.A.R.T. Threshold Data Structure

Byte	Description
0:1	S.M.A.R.T. structure version number
2	First Stored Attribute Number (i.e. "1" for RawErrorRate)
3	Threshold Value for first attribute
4:13	Reserved
14	Next Stored Attribute Number
15	Threshold Value for next attribute
16:25	Reserved
26:361	Attribute Number, Threshold and 10 reserved bytes for supported attributes, (max 30 collected Attributes, including above)
362:379	Reserved
380:510	Vendor Unique
511	Checksum

5.1.12 S.M.A.R.T. Command Transport (SCT)

The Element SSD supports the S.M.A.R.T. Command Transport (SCT). SCT allows the host to send commands, send and receive data, and receive status to and from the Element SSD using log page 0xE0 and log page 0xE1. SCT uses S.M.A.R.T. READ/WRITE LOG commands, READ/WRITE LOG EXT commands, or READ/WRITE LOG DMA EXT commands to access the log pages. For additional SCT information please reference ATA8-ACS.

5.2 SATA Commands

The SATA 3 specification is a super set of the ATA/ATAPI-7 specification with regard to supported commands. The Element SSD supports the following features that are unique to the SATA specification.

5.2.1 Native Command Queuing (NCQ)

The Element SSD supports the Native Command Queuing (NCQ) command set, which consists of

- READ FPDMA QUEUED
- WRITE FPDMA QUEUED

Note: With a maximum queue depth less than or equal to 32.

6 Certifications and Compliance

Table 6-1: Device Certifications

Certification/Compliance	Description
CE Compliant	Indicate conformity with the essential health and safety requirements set out in European Directives Low Voltage Directive and EMC directive.
FCC	Class A
TUV	Worldwide Safety Compliance
RoHS	Viking Technology (TM), Sanmina Corporation ("Viking") shall use commercially reasonable efforts to provide components, parts, materials, products and processes to customers that do not contain: (i) lead, mercury, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE) above 0.1% by weight in homogeneous material or (ii) cadmium above 0.01% by weight of homogeneous material, except as provided in any exemption(s) from RoHS requirements (including the most current version of the "Annex" to Directive\ 2002/95/EC of 27 January, 2003), as codified in the specific laws of the EU member countries. Viking strives to obtain appropriate contractual protections from its suppliers in connection with the RoHS Directives.
China RoHS	
Serial ATA	Requirements for logo.
EU WEEE Compliant	The Waste Electrical and Electronic Equipment Directive (WEEE Directive) is the European Community directive 2002/96/EC on waste electrical and electronic equipment (WEEE) which, together with the RoHS Directive 2002/95/EC, became European Law in February 2003, setting collection, recycling and recovery targets for all types of electrical goods.

7 References

- Viking Technology Environmental Test Report for 1.8" SSD
- Viking Technology EMI/EMC Test Report for 1.8" SSD
- Viking Technology EMI/EMC Test Report for 1.8" SSD
- Environmental Specification: MIL-STD-810F
- Serial ATA Specification, Revision 2.6 and Revision 3

Manual	1/2/2014
PSFS1XXXXGXXXX	Viking Technology
Revision B7	Page 59 of 60

8 Glossary

This document incorporates many industry- and device-specific words. Use the following list to define a variety of terms and acronyms.

Term	Definition
ATA	Advanced Technology Attachment
ATAPI	Advanced Technology Attachment Packet Interface
BER	Bit error rate, or percentage of bits that have errors relative to the total number of bits received
DIPM	Device Initiated Link Power Management. The ability of the device to request SATA link power state changes.
DMA	Direct Memory Access
eMLC	Enterprise Multi-Level Cell
EXT	Extended
FP	First Party
GB	Giga-byte defined as 1×10^9 bytes
HDD	Hard Disk Drive
Hot Plug	The removal or insertion of a SATA storage drive when the system is powered on.
IOPS	Input output operations per second
LBA	Logical Block Address
MB	Mega-bytes defined as 1×10^6 bytes
MLC	Multi-Level Cell
MTBF	Mean Time Between Failures
NCQ	Native Command Queuing. The ability of the SATA storage drive to queue and re-order commands to maximize execution efficiency.
NOP	No Operation
OS	Operating System
Port	The point at which a SATA drive physically connects to the SATA controller.
RMS	Root Mean Squared
RPM	Revolutions Per Minute
SAS	Serial Attached SCSI
SATA	Serial ATA
SFF	Small Form Factor
SLC	Single -Level Cell
S.M.A.R.T.	Self-Monitoring, Analysis and Reporting Technology: an open standard for developing storage drives and software systems that automatically monitors a drive's health and reports potential problems.
SSD	Solid-State Drive